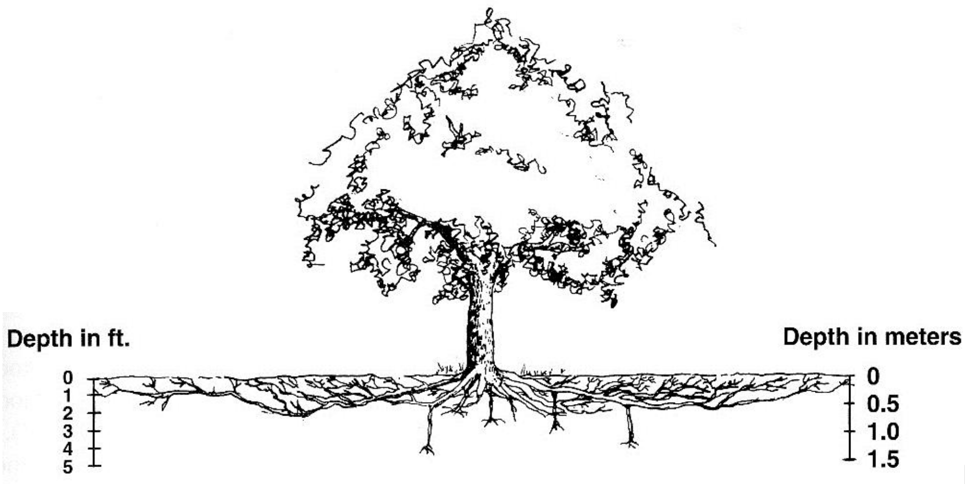
NREM/ENSC 301
Soils, Trees/Grasses & Forbs & Water
Interactions between Soils and Plants



Harris et al. 1999

Introduction

A tree is a plant that develops into the tallest, free-standing, perennial plant in the ecosystem and in the biosphere. It has a single stem at the base, is much branched above, has a much branched and even more extensive roots system below, and has well-developed, long-term cambial activity. Imagine yourself as a tree immobile in the spot you germinated in, unable to escape all the variations that the climate and weather throw at you. Your crown is located in a very fluid, low density medium that can blast you at high speeds carrying ice pellets, large rain drops and dust particles and can range in temperature from well below freezing to very hot in the matter of hours or days and that transmit ultra violet and other radiation that is needed for photosynthesis but an also burn your tissue, and a medium that when it is not saturated with liquid droplets is so dry that it literally sucks the water out of your leaves.

That is your crown, now think about the other quarter of your mass that exists in a very dense medium so dense and full of obstructions that your growing root tips must move through torturous paths of pores that may be very low in oxygen and high in carbon dioxide or saturated with water. This medium does not go through the temperature or moisture swings of the above ground medium but this medium has the added hazard of more biota feasting on your body parts. We can imagine that the above-ground part of the tree can develop a strategy of regularly appearing and balanced branches and leaves modified by the stresses of high winds or crowded neighborhoods. No such organized strategy works below ground because the medium is variable and dense requiring that the root system is very opportunistic to be successful. The predictably designed above-ground part of the tree depends on the highly plastic below-ground medium for support, water and nutrients. It is this medium and the response of the tree to its variability that we find difficult to envision.

Now think of organization of native grasses and forbs that also exist in these two highly different media. Their strategies for coping are very different from those of trees and shrubs. Many of them are annuals who only have to exist in each medium for the time it takes to produce seed for their next generation. Many of these plants have developed seeds that are able to lie dormant in the seed bed of the soil surface for many years until conditions are optimal for their germination and growth. Most of the perennial plants have their regenerative growing points at or just below the soil surface and allow their tops, which are exposed to the high variability of temperature and moisture in the atmosphere die before the extremes of cold occur. Most of their biomass is below ground in fibrous roots or bulbs and corms and other fleshy structures. These are often located in the surface soil where they are protected by the moderating conditions of the soil. The soil provides not only the structural medium in which all of these plants grow but also supplies most of the water and nutrients that are critical to their survival. Thus the highly variable soil is a unique medium that is difficult to envision in its undisturbed state. The objective of this handout is to help you improve your vision of this complex, living medium.

Learning Outcomes

After reading and studying this handout and the lab handouts you should be able to:

a) define what a soil is

b) identify the factors that control soil formation and how each one functions

c) describe the major soil orders of North America

d) identify the effects of soil texture, structure, porosity, bulk density, organic matter content, cation exchange capacity and base saturation, reaction, horizonation, and depth on infiltration and percolation of water, the soil biotic community, root system development, plant nutrition and water uptake and general growth of trees

e) describe the structure and function of a typical tree root system and explain how that form adapts to different kinds of soil and topographic conditions

f) describe how soil characteristics change in the different topographic positions of the landscape and how that influences water movement and development and growth of trees

g) describe the impact of management on soil characteristics and the resulting changes in water movement and tree growth.

Vocabulary You Should Know By The End

Soil
Cliprot
Soil texture
Soil Structure
Peds
Aggregates, micro & macro
Slaking
Flocculation
Parent material
Weathering
Elluviation
Illuviation
Master Horizons (A, E, B, C, R)
L, F, H, (Oi, Oe, Oa)
Mull humus
Mor humus
Moder humus
Cation exchange capacity (CEC)
Macro & micro nutrients
Exchangeable ions
Base saturation
Gravitational water
Capillary water
Field Capacity
Permanent wilting point
Hygroscopic water
Available water
Soil biomass
Exudates
Leachates

Light fraction soil organic matter
Heavy fraction soil organic matter
Coarse woody debris
Humus
Protista
Microbes
Soil fauna & flora
Saprophytes
Mycorrhizae
Ectomycorrhizae
Endomycorrhizae
Vesicular-arbuscular mycorrhizae
Fungal mantle
Hartig net
Arbuscules, vesicles
Rhizosphere
Heart root system
Tap root system
Flat root system
Sinker roots
Fine feeder roots
Primary root anatomy

What is Soil?

So what is soil and why is soil not dirt? *Soil is a natural body of unconsolidated mineral and organic matter (living and dead) that develops unique characteristics in place, over time and in response to the parent material, climate, topographic position, and plant and animal community that it is developing in.* Soil is a dynamic natural body that is alive with roots, fungal hyphae and myriads of meso and microfauna and flora that are intimately involved in controlling its shape and function. Natural soil is a highly porous soil that occupies the top few centimeters to more than three meters of the earth's crust and serves as a medium for development of root systems that support plant growth as well as a medium (natural sponge) for water storage and movement. Dirt with it's negative connotation refers to soil that has been dramatically disturbed usually through movement. Dirt can once again become soil given enough undisturbed time to develop the unique characteristics of a soil medium.

As mentioned, soil is a function of the climate, parent material, topographic position, and plants and animals it develops with over a given period of time. These relationships are shown in the following relationship:

Soil ~ f(cli, p, r, o, t)

Where: **cli** = climate
p = parent material
r = relief (topography)
o = organisms (plants, animals, insects, etc.)
t = time

The combination of these factors produce a unique set of horizons (layers) in each part of the landscape that develop in response to the movement of water and materials vertically and laterally through the soil profile. Five master soil horizons are recognized and given letters of O, A, E, B and C (Figure 1, Brady & Weil, 1999).

The **O horizons** are composed of organic matter that is generally above the mineral soil. The organization and depth of the O horizons varies with the plant community. Often missing or very thin in prairie soils because of rapid decomposition they are found in forests. However, even in forests they can vary from on very thin layer to up to three well developed ones. The top horizon on these situations is the **Oi horizon** (also called the **L** or **litter layer**) and consists fo recognizable plant and animal parts that are only slightly decomposed. The **Oe horizon** (also called the **F** or **fermentation layer**) consists of materials that are partially decomposed and the **Oa** horizon (also called the **H** or **humus layer**) consists of highly decomposed material with only the very most resistant parts still not decomposed. Under many hardwood forests the Oe and Oa layers may be poorly developed giving rise to what is called a **“mull” forest floor**. In this situation the organic matter is rapidly mixed with the surface mineral soil and no clear line of demarcation may be evident between the O horizons and the A. Under many conifer stands, where decomposition is slow all three layers may be present giving rise to a **“mor” forest floor**. In this situation there is usually a very clear line of demarcation between the Oa horizon and the mineral soil. This kind of floor provides the best protection of the mineral soil from direct raindrop impact. A floor lies between those two is called a **“moder” forest floor** and is often found under oak or mixed oak/hickory forests.

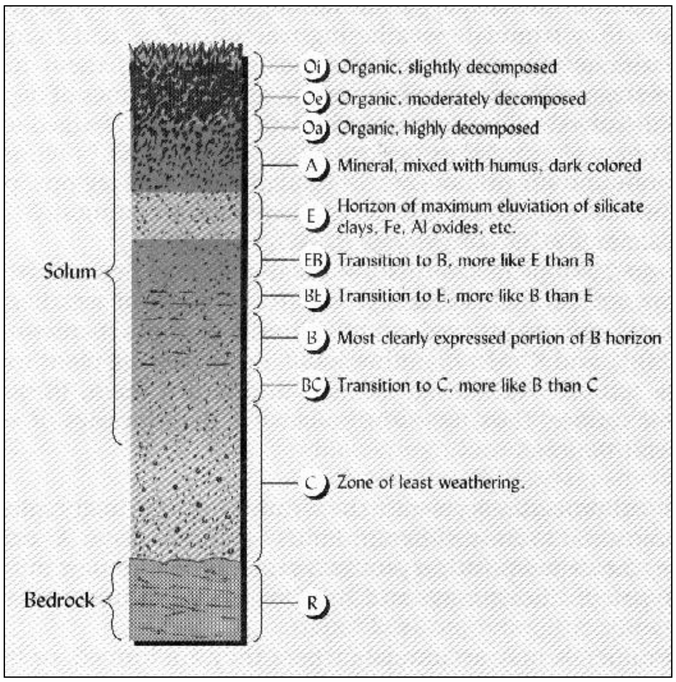


Figure 1. Major soil horizons that may be formed in a well-drained soil in the temperate zone. Any particular soil may not have all of these profiles or may have even more detailed sub-horizons and depths of any of the horizons will vary from site to site. The O horizons are not considered part of the mineral soil. The Solum includes the A, E, B and some cemented layers of the C. R layers are consolidated rock, with little evidence of weathering.

The **A horizon** is the top most mineral horizon that may contain 5% or more organic matter. This organic matter give rise to the darker color of these horizons and usually comes form the decomposition of short-lived fine roots. This horizon often has coarser texture than those below because the finer materials have been translocated down to the lower horizons. In undisturbed soils these horizons have well developed **granular structure** with large numbers of macropores that allow rapid infiltration of precipitation and diffusion of oxygen from the atmosphere. Most of the short-lived fine roots of the plant community are located in this horizon because of the aeration and the high nutrient availability.

The **E horizon** is the zone of maximum leaching or **eluviation** (washed out) of clay, iron and aluminum oxides leaving behind concentrations of resistant minerals like quartz in sand and silt fractions. These horizons are usually lighter in color than the A or B horizons and have **platey structure**. They are frequent found under forests because much of the organic matter added to the soil is from the top from canopy litter and fine roots located near the mineral soil surface where decomposing nutrients from the O horizons are available. The E horizon is seldom found under grasslands because of the deep fibrous root systems with high turnover that contributes organic matter throughout greater depths of the soil and lesser amounts of percolating rainfall for leaching.

The **B horizon** is the horizon where materials that have moved from the upper horizons accumulate by the process of **illuviation** (washed in). In these layers the clay and iron and aluminum oxides that were leached from the E horizon can be found often coating the **blocky peds** (a structural unit). Under dry climates accumulations of calcium carbonate may also be found. Films of clay, iron and aluminum oxides can give this soil a darker brown or redder color than the E horizon. Because fo these accumulations the percolation rates of water is often less than those in the A horizon and water that infiltrated and precolated vertically into and through the A horizon now may also move laterally along the upper face of the B horizon.

The **C horizon** is the unconsolidated material that lies below the A and B horizons and is the weathered parent material in which the soil is forming. This horizon lies below the biologically active portion of the soil. It may have **massive structure** if any exists.

Different combinations and thicknesses of these horizons result from different activities of the soil forming factors at specific locations in the landscape and give rise to different soils that are identified as soil series for management purposes. Soil series translate into soil mapping units on USDA Natural Resources Conservation Service (NRCS) maps.

Parent materials are the geologic or organic precursors to the soil. The soil forms in these materials under the influence of the other variables in the soil forming equation given above. Parent materials can be classified as residual (bedrock and minerals that have not been moved) or transported and deposited materials. Figure 2.10 (Brady & Weil, 1999) identifies the various kinds of parent material on the basis of the vectors that transport and deposit them. Organic soils can be developed in bogs and fens where long time accumulation of organic matter and slow decomposition rates provide the parent material for the soils. Parent materials control much about a soil, the rate of development, the texture and the basic nutrition to name a few.

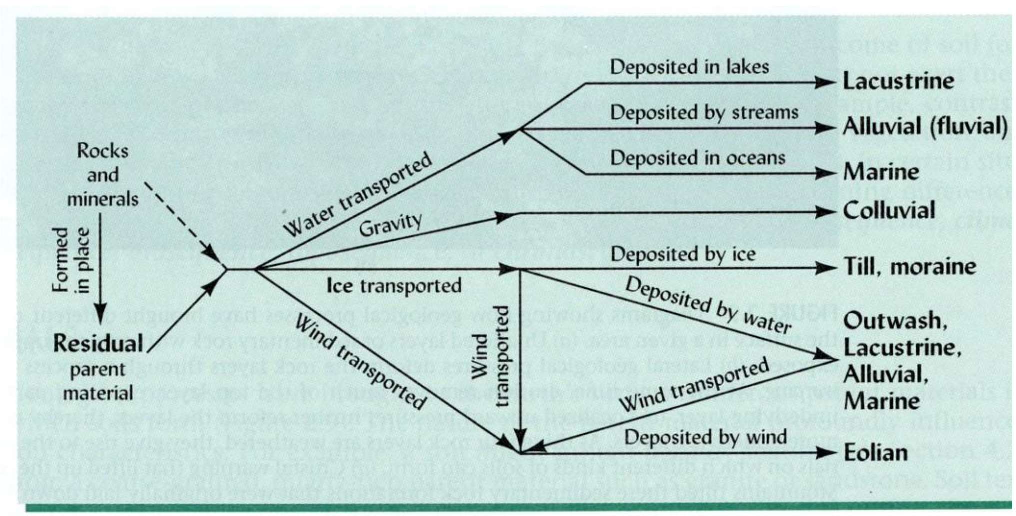


FIGURE 2.10 How various kinds of parent material are formed, transported, and deposited.

Relief or topography work closely together with parent material to exert an influence on soil formation because of their impact on water and material movement (Figure 2). Deep soils tend to develop in the residual or wind and ice transported parent material on the summit and the water transported alluvial parent material of the flood plain. Shoulder and back slope soils tend to be shallower because gravity erodes soil down slope. Soils of the foot slope tend to be deeper again because they are forming in gravitationally deposited colluvial parent material derived from the back slope and shoulder. Soils on the back slope, foot slope and on the toe slope of the flood plain tend to be more poorly developed because of their ever changing parent material – surface soils are eroded from the back slope and deposited on foot slope and flood deposited materials are deposited on the toe slope.

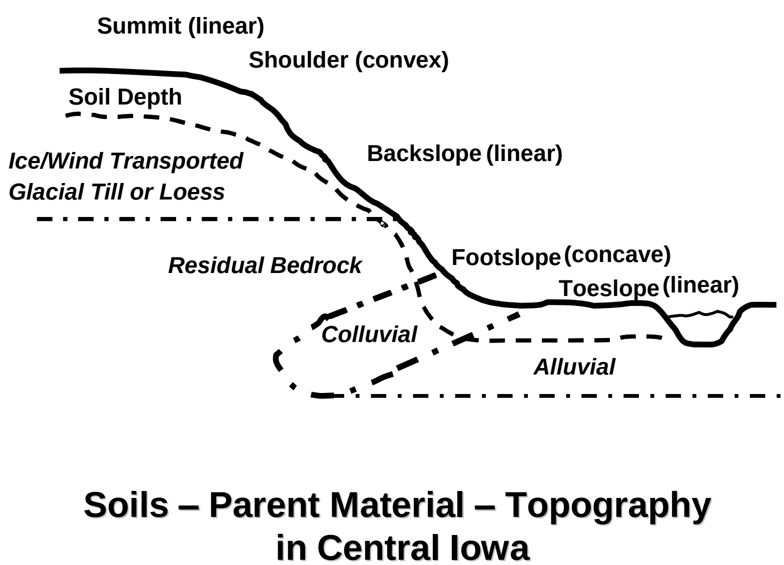


Figure 2. Interaction between slope position, parent material and soil depth in typical Central Iowa landscapes.

Climate plays and enormous role in soil formation. It provides the precipitation, the water, for chemical, physical and biological processes. Rainfall provides water for leaching materials from upper to lower horizons or for eroding surface layers down slope. A change of 10 C in temperature can double the rate of biochemical processes such as decomposition and root growth. Both of these variables help determine the kind of plant and animal communities that can be maintained in an area and the rate at which soils form. These effects are both regional and local. At the regional scale we would expect soils in the humid southeastern United States to develop faster because of higher rainfall that leaches materials through the profile and because of higher temperatures which stimulate more biological activity. At a local scale microclimate differences can be seen in relation to slope and aspect. South-facing slopes are usually warmer and drier than north-facing slopes. South-facing slopes in areas of frost will experience more freeze-thaw action than north-facing slopes resulting in more physical weathering and often less steep slopes from the increased erosion.

Organisms also play a critical role in soil development. Soils formed under forests with about three quarters of their biomass above-ground and one quarter below-ground are often not as deep but may have more highly developed horizons than a soil formed under prairie with one third of its biomass above-ground and two thirds below-ground (Figure 3) . Forested soils usually develop a thin A horizon because major organic matter and nutrient additions are contributed by the O horizon. Leaching rain water creates both a well defined E and B horizon. Prairie soils developing under less rainfall and with their major organic matter contributed below ground develop a thick A horizon that is difficult to leach enough to create an E horizon and often a less developed B than the forested soil. Animals also play a key role in decomposing, moving and mixing organic matter and mineral soil and in providing additional organic matter.

Finally, all of these variables acting together do so under the constraints of **time**. Where they are able to interact for longer periods of time the soil is usually more developed (more horizonation). Remember that here we are referring to time in terms of processes working on the parent material in conjunction with the other variables where no new material is added. Flood plain and back and foot slope soils are usually younger than summit and shoulder soils because they are frequently disturbed by the additions of new depositions of parent material. Soils developing for the same length of time but under slower operating processes because of climatic variables such as dry and cold conditions are younger than those developing under warmer and wetter climates for the same geologic time period.

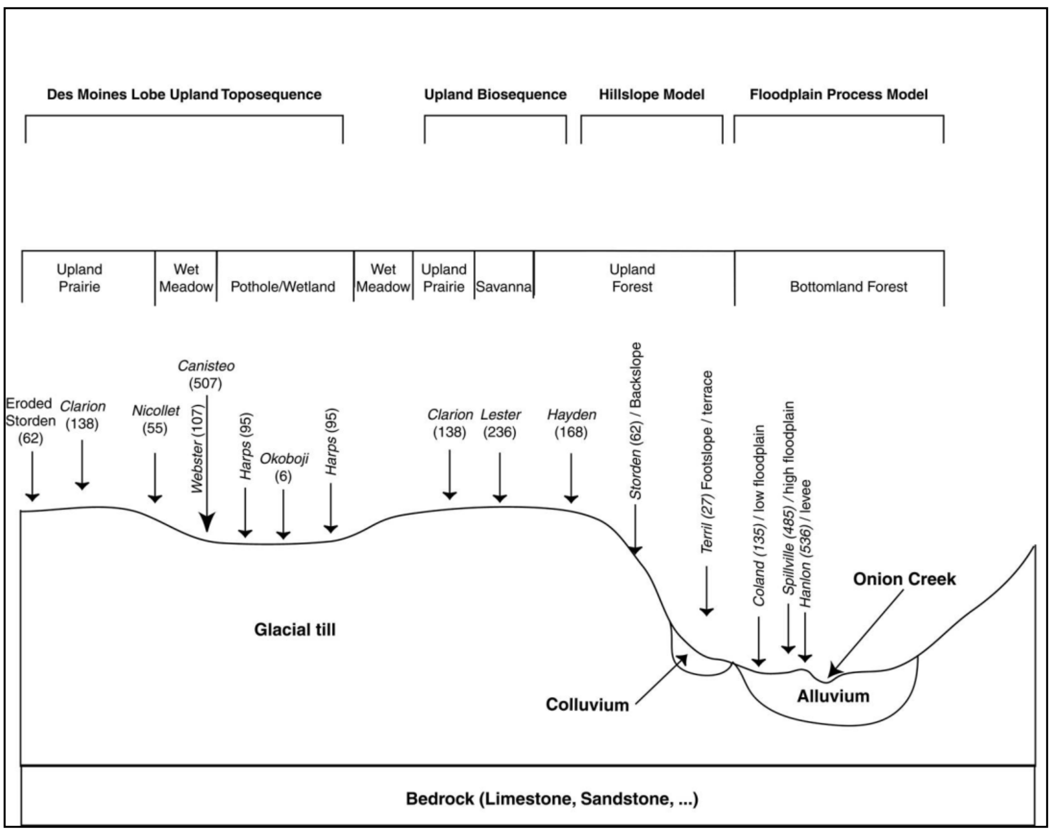


Figure 3. Soil landscape model for central Iowa, USA. Notice the relationships between plant communities and soils. The numbers associated with soil names are soil mapping unit numbers found in the Story County, Iowa Soil Survey (Dewitt, 1984).

The interactions between all of the soil forming factors create a wide diversity of soils across the landscape. This diversity is predictable and very important to understand for any natural resource professional because good landscape management depends on understanding the potential of the natural resources of the land. Successful restoration activities depend heavily on understanding what the natural condition of the landscape was and how present and past land-use practices are changing those conditions. It is therefore as important to know the soils of an area as it is to know the taxonomy of the plants and animals of an area since the latter depend so heavily on soils for their expression. The NRCS provides a good overview of soil variability across landscapes in their published County Soil Surveys. Patterns of soils typically found from the uplands, down the slopes and into the flood plains of central Iowa are shown in Figures 4, 5, 6 (Dewitt, 1984).

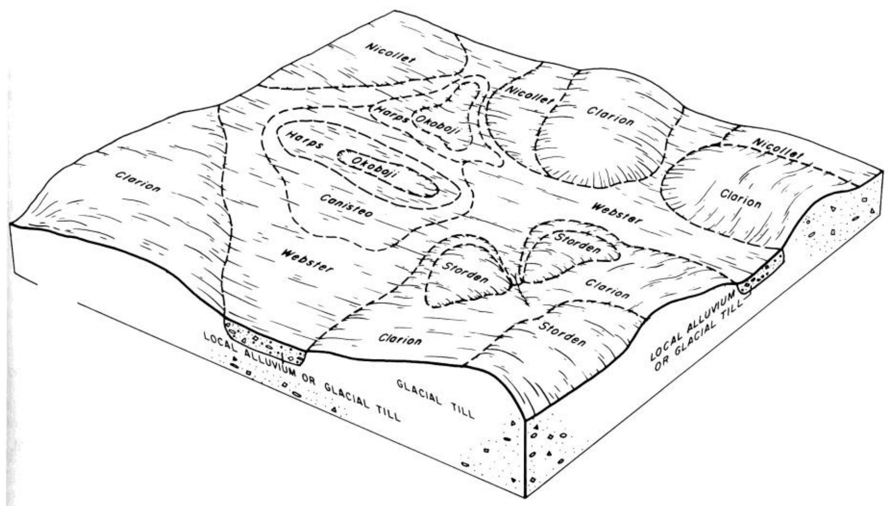


Figure 4. Patterns of soils and parent material in the Clarion-Webster-Nicollet Association of prairie and wetland dominated uplands of Central Iowa (Dewitt, 1984)

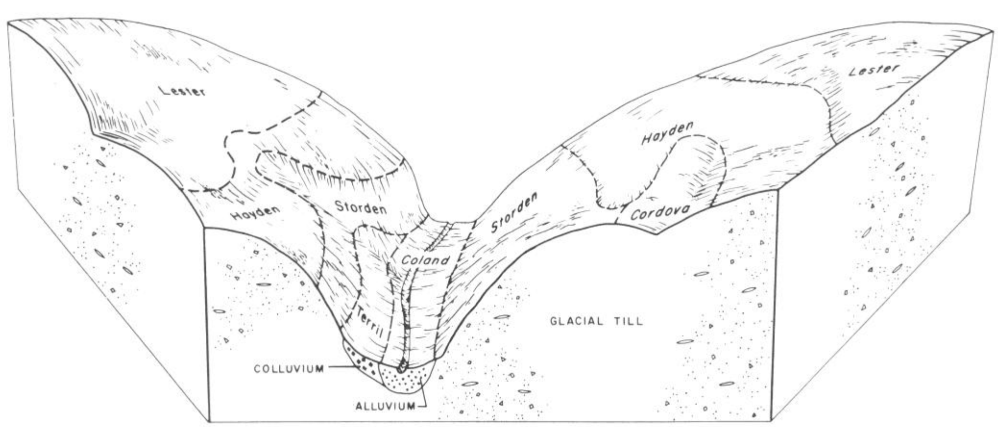


Figure 5. Patterns of soils and parent material in the Hayden-Lester-Storden Association of savanna and forest dominated hillslopes of Central Iowa (Dewitt, 1984)

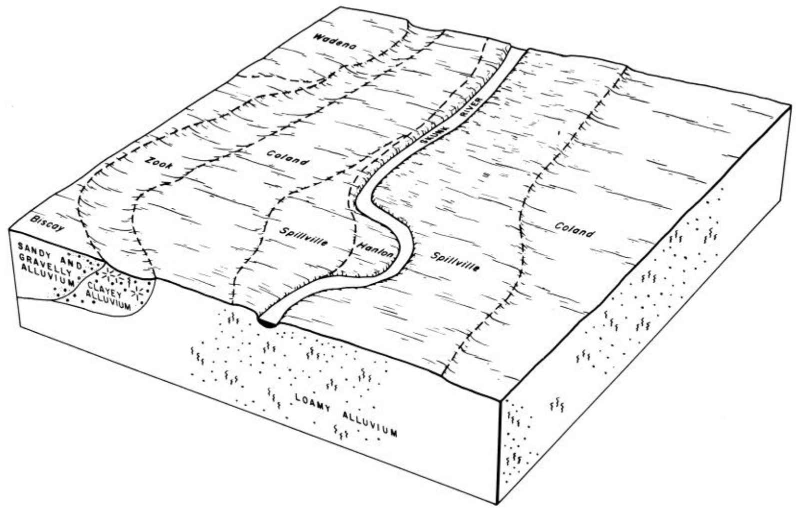


Figure 6. Patterns of soils and parent material in the Coland-Spillville-Zook Association of s forest dominated flood plains of Central Iowa (Dewitt, 1984)

Combining the knowledge of soil patterns across a landscape with the growth requirements and performance of native plant species allows the natural resource professional to design and establish successful plant communities across the landscape. The Woodland Suitability Classifications attached to this handout provide recommended tree species for given soils in Iowa. Prairie and wetland species recommendations can be found in Thompson, 1993.

Soil Physical Properties

Texture - Weathering of parent material is the result physical processes such as freeze-thaw and leaching and by the chemical interactions of acids produced by the hydrogen ion in rainfall (carbonic acid is produced) and organic acids that result from the decomposition of plant material. The minerals produced by weathering of the parent material are divided into clay (< 0.002 mm in dia.), silt (0.002 - 0.05 mm) and sand 0.05 - 2 mm) and give rise to soil texture. Primary minerals (silt and sand) are the result of simple weathering physical and chemical weathering. Weathering of some minerals produces recombined or secondary minerals of the clay fraction. Relative comparison of the size of soil separates is shown in Figure 5.11 (USDA Forest Service, 1961)

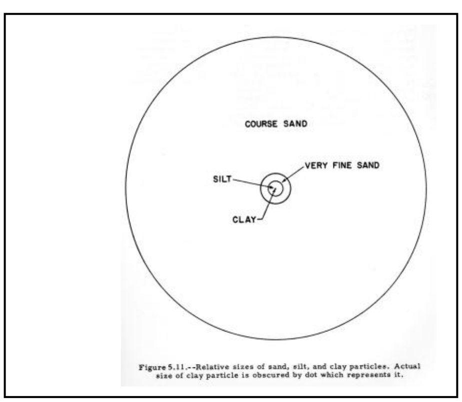


Figure 5.11.--Relative sizes of sand, silt, and clay particles. Actual size of clay particle is obscured by dot which represents it.

Figure 7. Relative sizes of sand, silt and clay. The actual size of the clay particle is obscured by the dot which represents it.

Clay is unique in that it has huge surface area because of its platy structure. A spoonful of clay particles has a surface area equivalent to the area of a football field. This is important because surface area is an indicator of the amount of water and other substances that can be adsorbed by the particles. The large surface area of clay accumulates electrical charges that are extremely important in plant nutrition because they attract and hold cations such as calcium (Ca^{++}) magnesium (Mg^{++}), potassium (K^{+}) and ammonium (NH^{-4}). Because of their high surface area and electrical charges clays are very interactive with their environment. They strongly complex with organic matter producing an organo-mineral material that helps create soil from loose mineral particles by producing soil structure and providing nutrient and water holding capacity. Table 4.1 (Brady and Weil, 1999) indicates some of the behavioral characteristics of soils dominated by different soil separates.

TABLE 4.1 Generalized Influence of Soil Separates on Some Properties and Behavior of Soils.[a]

	Rating associated with soil separates		
Property/behavior	*Sand*	*Silt*	*Clay*
Water-holding capacity	Low	Medium to High	High
Aeration	Good	Medium	Poor
Drainage rate	High	Slow to Medium	Very slow
Soil organic matter level	Low	Medium to High	High to Medium
Decomposition of organic matter	Rapid	Medium	Slow
Warm-up in spring	Rapid	Moderate	Slow
Compactability	Low	Medium	High
Susceptibility to wind erosion	Moderate (high if fine sand)	High	Low
Susceptibility to water erosion	Low (unless fine sand)	High	Low if aggregated, high if not
Shrink-swell potential	Very Low	Low	Moderate to very high
Sealing of ponds, dams, and landfills	Poor	Poor	Good
Suitability for tillage after rain	Good	Medium	Poor
Pollutant leaching potential	High	Medium	Low (unless cracked)
Ability to store plant nutrients	Poor	Medium to high	High
Resistance to pH change	Low	Medium	High

[a] Exceptions to these generalizations do occur, especially as a result of soil structure and clay minerology.

Soils consisting of only one soil separate are hardly ever found in nature. Instead soils consist of different proportions of the three separates and these different proportions are classified into broad textural classes. The textural triangle (Figure 8, Brady and Weil, 1999) provides a method of determining what textural class a soil is in. It is often suggested that a loam soil provides ideal conditions for plant growth. Note that a loam is not an equal mixture of each of the soil separates.

Field determination of texture can be used to place soils into a textural class especially after practice with known textural samples. The first step to doing a field determination is to take a walnut sized chunk of soil and moisten it slowly and work it between your fingers until it is totally moist but not glistening. This may require a few minutes time and added water. As you work the soil notice its stickiness and smoothness. Samples high in silt feel smooth and silky like flour and show little stickiness. Soil with high contents of sand feel and sound gritty and rough. Squeezing the soil between your thumb and forefinger to make a ribbon can be used to assess the amount of clay present. Brady and Weil (1999) suggest the following interpretations of your wetted sample:

1. Soil will not cohere into a ball, falls apart: **sand**
2. Soil forms a ball, but will not form a ribbon: **loamy sand**
3. Soil ribbon is dull and breaks off when less than 2.5 cm long, and
    a. Grinding noise is audible; grittiness is prominent feel: **sandy loam**
    b. Smooth, floury feel prominent; no grinding audible: **silt loam**

c. Only slight grittiness and smoothness; grinding not clearly audible: **loam**

4. Soil exhibits moderate stickiness and firmness, forms ribbons 2.5 to 5 cm long, and
   a. Grinding noise is audible; grittiness is prominent feel: **sandy clay loam**
   b. Smooth, floury feel prominent no grinding audible: **silty clay loam**
   c. Only slight grittiness and smoothness; grinding not clearly audible: **clay loam**
5. Soil exhibits dominant stickiness and firmness, forms shiny ribbons longer than 5 cm, and
   a. Grinding nose is audible; grittiness is dominant feel: **sandy clay**
   b. Smooth, floury feel prominent; no grinding audible: **silty clay**
   c. Only slight grittiness and smoothness; grinding not clearly audible: **clay**

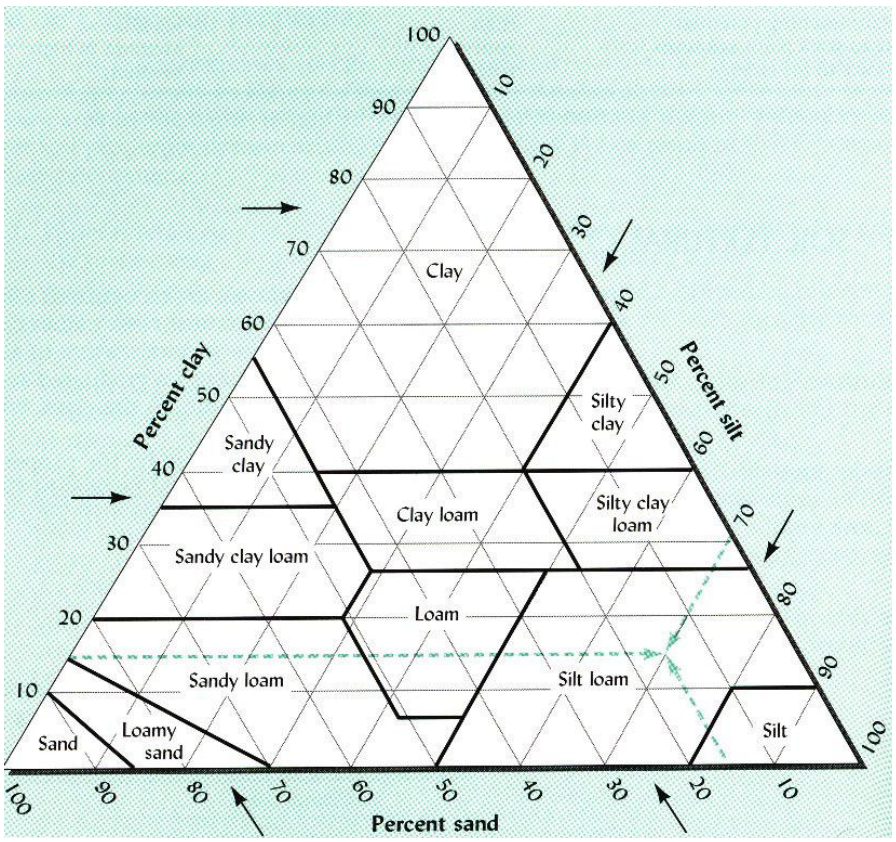


Figure 8. The textural class triangle. The arrows outside the arrow show which lines to follow with a given percent of one of the soil separates. In this example follow the dotted lines for a soil with 15% sand, 15% sand and 70% silt and notice that the lines intersect in the silt loam texture class.

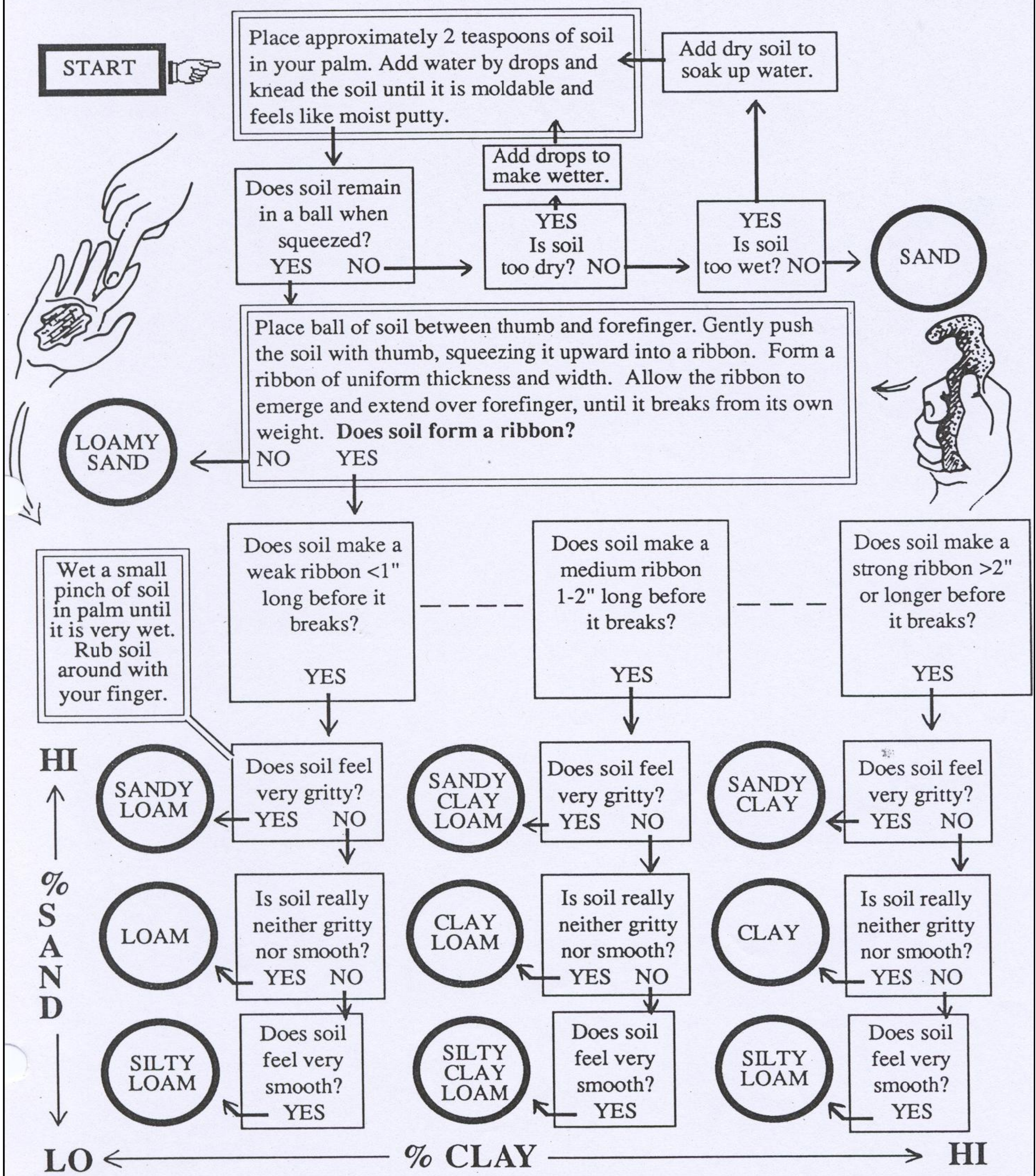
Many field professionals are able to get close to predicting soil texture using simple field texture guides like the one below. More detailed determinations of texture require lengthy laboratory analyses that provide specific percentages of sand, silt and clay but that often provide no more useful information for field management prescriptions than an in-field texture test can do.

Student page

KEY TO SOIL TEXTURE BY FEEL

[Adapted from flow chart by Steve Thien, 1979, source unknown.]

Begin at the place marked "Start" and follow the flow chart by answering the questions, until you identify the soil sample.



Soil texture can be used to help identify planting sites for specific plant species. Table 2 shows an example from Wisconsin and Figure 10.2 from Louisiana.

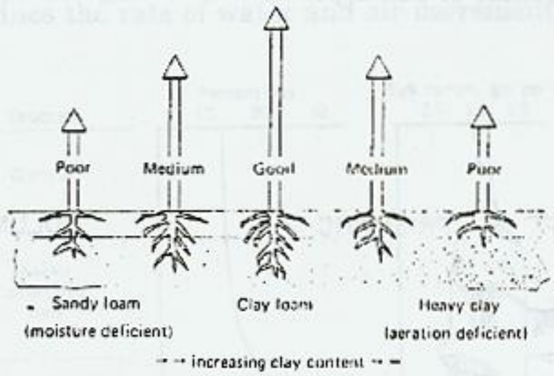


FIGURE 10.2. Effect of subsoil texture on growth of loblolly pine in south Arkansas and north Louisiana (from Zahner, 1957).

Table 2. Texture recommendations for reforestation on upland soils in northern Wisconsin.

Texture Recommendations for Reforestation on Upland Soils in Wisconsin

% Silt + Clay		Species Recommended
<5		(wind erosion control only)
5-10		Jack pine, red cedar
10-15	Increasing Demand for Water & Nutrients ↓	Red pine, Scotch pine, Jack pine
15-25		All pines
25-35		White pine, Eur. Larch, yellow birch, Red oak, shagbark hickory
>35		White spruce, white cedar, white ash, basswood, hard maple, white oak, black walnut

Source: Foth 1990 after Wilde

Structure – soil structure represents the arrangement of clay, silt and sand particles into **peds** or **aggregates**. Numerous processes are involved in "gluing" together these particles into large and small macroaggregates and the number and arrangement of these aggregates controls the size and amount of pores in the soil. Porosity is one of the most critical features of a soil because it greatly influences water and air movement, heat transfer and the ability of roots to grow through the medium. We will discuss how aggregates form later. Here we want to identify the major kinds and locations of aggregates or peds in undisturbed soils. Four common types of aggregate structure can be found in soils. They are shown in Figure 9 (USDA Forest Service, 1961).

Granular structure is found in the A horizon and consists of loosely packed spherical peds that provide the highest levels of porosity providing high rates of water infiltration. **Platy structure** is found in the E horizon and consists of horizontal plates that may begin to restrict the rapid downward movement of water through the granular structure of the A horizon. Vertical water movement may begin to move laterally at this interface. Compaction from heavy machinery in high clay soils can create platy structure. **Blocky structure** is found in the B horizon and consists of larger rectangular structures that fit together like a puzzle. While this structure provides subsoil porosity that is very important to good soil aeration, drainage and root growth, the larger size of these peds, reduces the amount of macropore space in the profile and percolation rates are slowed from those in the A and even the E horizons, resulting in the lateral movement of some percolating water. Prismatic and columnar structures are usually found in the B horizon of arid and semi-arid soils or may be found in some poorly drained soils or fragipan soils of Iowa.

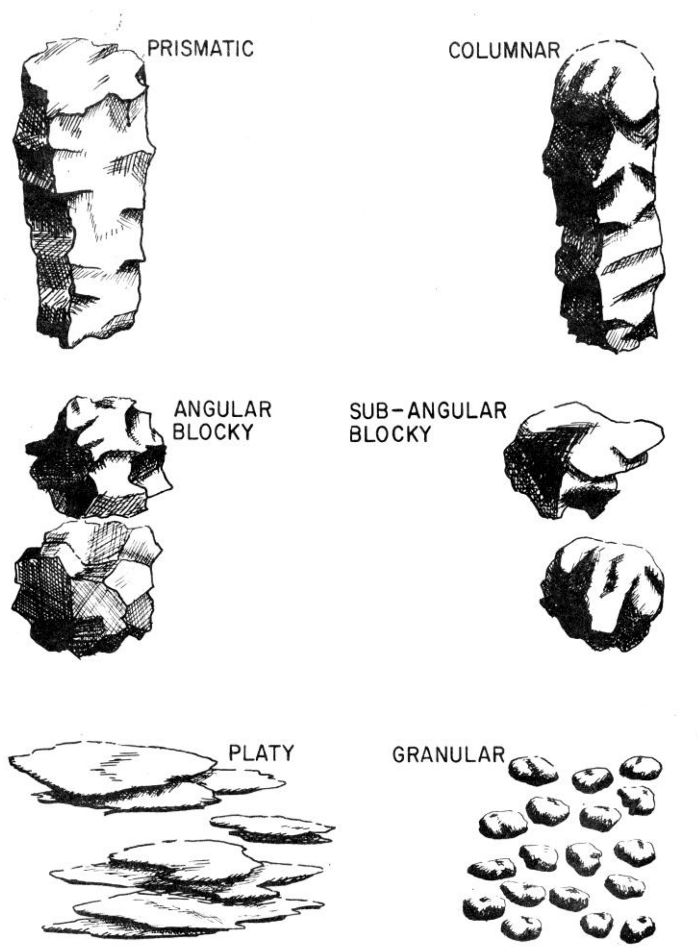


Figure 9. Types of soil structure.

Land-use practices such are agricultural tillage, grazing, timber harvesting, etc. have their major impacts on the structure of soil. In most cases these practices crush the peds in the surface soil, especially the granular structure of the A horizon. The result of this activity is a loss of macropores and an increase in bulk density.

Bulk density is the mass of unit volume of dry soil. Here that unit of soil is a specific volume of field soil that is carefully removed, dried and weighed. Generally, undisturbed soils under native vegetation have low bulk densities while soils under cultivation, grazing or recent forest harvesting have higher bulk densities. Fine-textured soils such as silt loams, clays and clay loams generally have lower bulk densities than sandy soils and soil lower in the profile usually has higher bulk densities than those in the surface. This latter difference is probably due to lower organic matter, less aggregation and fewer plant roots. Figure 4.25 (Brady & Weil, 1999) shows differences in the volume of organic matter, sand, silt, clay, and micro- and macro-pore space in a sandy loam soil and a silt loam soil with good structure and one with poor structure. Note the impact of poor management on macro-structure in the silt loam soil.

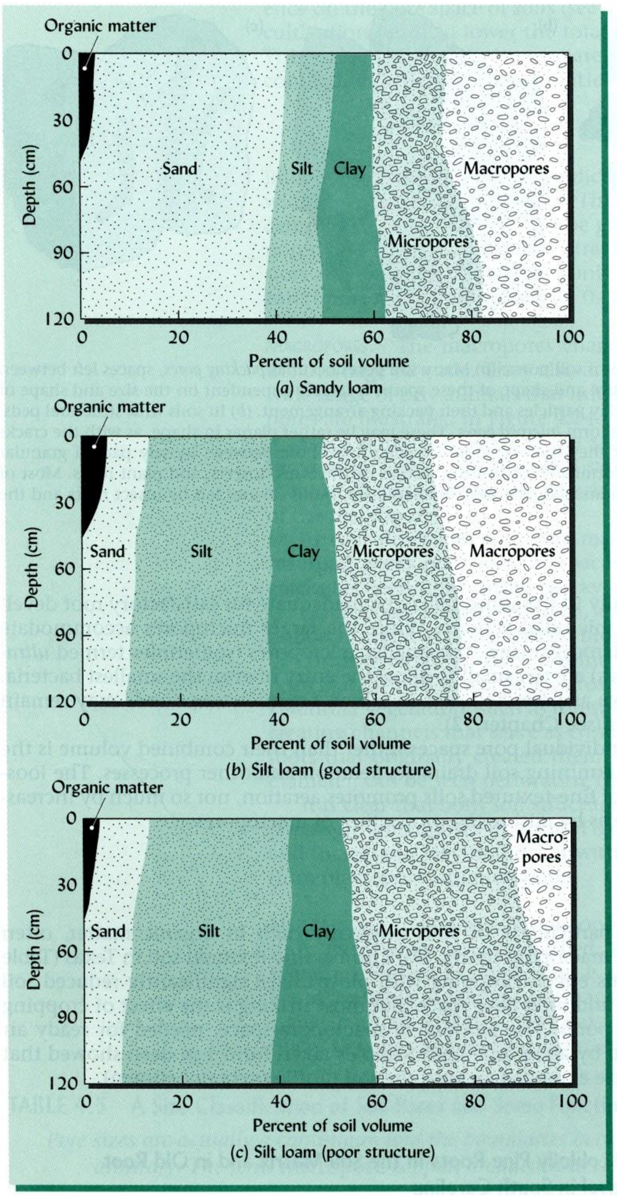


FIGURE 4.25 Volume distribution of organic matter, sand, silt, clay, and pores of macro- and microsizes in a representative sandy loam (*a*) and in two representative silt loams, one with good soil structure (*b*) and the other with poor soil structure (*c*). Both silt loam soils have more total pore space than the sandy loam, but the silt loam with poor structure has a smaller volume of larger (macro) pores than either of the other two soils. Note that at the lowest depths in both silt loams, about one-third of the mineral matter is clay, giving the lower horizons enough clay to be classified as silty clay loams.

The bulk density of uncultivated forest or prairie surface soil lies between 0.8 and 1.2 Mg/m^3 (to convert Mg/m3 to lb/yd^3 multiply by 1686). Cultivated clay loam and silt loam soils have surface bulk densities of between 0.9 and 1.5 Mg/ m^3 and cultivated sandy loam and sandy soils between 1.2 and 1.7 Mg/ m^3. Root penetration by extending root tips is inhibited when soil bulk densities reach between 1.6 and 1.7 Mg/ m^3. Using a bulk density of 1.25 Mg/ m^3 results in a soil weight of about 80 lbs/ft^3 or about 2 million lbs per acre-furrow slice 6-7 in deep.

Conventional forest harvesting can effect 20-40% of the forest floor and increase bulk densities from 1.2 to 1.5 Mg/ m^3 and even more on skid trails. Note that this is very close to the density at which root penetration is inhibited. Root penetration is even more restricted when high bulk density soils are dry since soil strength is higher in dry than moist soils meaning the soil resists deformation by the growing root tip.

Bulk density provides a measure of total porosity but soil pores come in many sizes. At the simplest level of organization, pores are broken into **macro-** and **micro-pores** with macro-pores including pores that are 0.08 – 5+ mm in diameter and micro-pores being < 0.08 mm in diameter. Macro-pores are usually found between granular peds and are large enough to allow water to drain by gravity (these pores are mostly empty at field capacity soil moisture), allow air to effectively diffuse through the soil, allow roots to grow into and through them and provide habitat for soil animals. Pores between 0.03 and 0.08 mm in diameter retain water after drainage, transmit water by capillary action, accommodate fungi (especially those involved in mycorrhizae) and root hairs. Pores between 0.005 and 0.03 mm in diameter are generally found in peds and hold water that plants can use and accommodate most bacteria. Pores < 0.005 mm in diameter hold water that plants can not use and exclude most microorganisms. By comparison fine roots are those < 4 mm in diameter, medium roots, 4-20 mm in diameter and coarse roots > 20 mm in diameter.

Bio-pores are large pores created by roots, earthworms and other organisms and are very important for transport of water and materials and for growth of root systems. These pores are not only large in diameter but are usually continuous for great lengths allowing rapid movement of materials. Biopores left following the death of roots can persist for a long time allowing other roots to occupy them. As can be seen from this discussion, bio-pores and macro-pores are very important to plant growth, water and air movement and a healthy animal community. Micro-pores are usually filled with water but even when they are not are too small to facilitate much air movement. Water movement is slow in the micro-pores in is unavailable to plants in the smaller ones. Cultivation dramatically reduces macro-pores space by destroying structure and other activities such as timber harvesting, and urban home lawn and park soil recreational use compacts the soil reducing macro-pores. All of these activities challenge the healthy growth of plants.

Soil water is essential for plant growth. Water movement through the soil is primarily a function of soil porosity. Water moves through macro-pores in response to gravity. Water in micro-pores is held against gravity by adhesive (attraction between water and soil) and cohesive (attraction between water molecules) forces. The smaller the pore the more tightly the water is held and pores with diameters smaller than 0.005 mm hold water no longer available to plants called **hygroscopic water**. When the soil is saturated after a long rain storm all of the pores are theoretically filled with water and no air is available for root respiration. If this condition were to persist root growth in most plants would cease. Plants that have special aerenchyma tissue that allows air transfer from above the soil line down into the roots are an exception.

However, water drains quickly from the macro-pores under the force of gravity. When these pores are empty the soil is said to be at **field capacity**, the ideal condition for growth. This condition generally occurs between 24-48 hours after saturation from a rain event. The water that drained in response to gravity is called **gravitational water**. As the soil continues to dry the water is removed from larger micro-pores. The smaller the micro-pores the more tightly the water is held by adhesion making it difficult for the plant to extract the water for transpiration. Stomates begin to close down for periods during the day curtailing photosynthesis. As water gets harder to extract the plant begins to wilt. At the **permanent wilting point** the plant can no longer rehydrate itself over night and for practical purposes dies. The water held at tensions between field capacity and permanent wilting point is called **available water**. The tension at which this occurs differs for different plant species. While individual leaves on trees may reach the permanent wilting point seldom does the whole tree reach that point. There is significant water storage in the living tissues of the tree stem that can supply water throughout the tree. In addition to that the rooting volume of most large trees exploits so much soil that it usually has access to some available soil moisture. Large portions of the fine roots system of trees can become suberized (inactive) during droughts and some of that mass can be shed (dies) to reduce the water and respiratory needs of the plant but trees seldom die from one or two years of drought unless they are planted way off site. Figure 7.5 shows the daily changes in water potential in a plant as the soil dries following a rain event. Note that the plant rehydrates itself over night but that the time of rehydration gets shorter and shorter each day until such time when the plant can no longer completely rehydrate itself as at day 5. Again this curve applies more to herbaceous plants or individual leaves of woody plants.

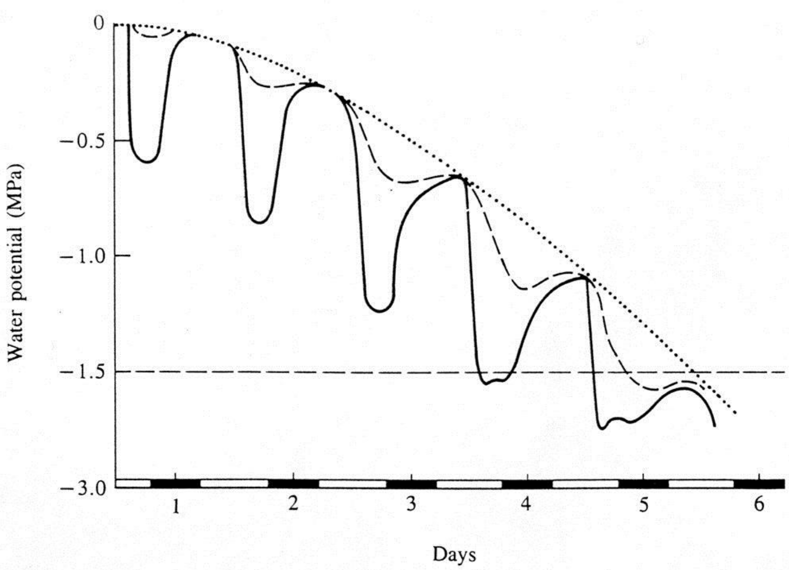


Figure 7.5 Diagram showing probable daily changes in leaf (——) and root (−−) water potential of a transpiring plant rooted in drying soil (····). The dark bars indicate darkness. (After Slatyer, 1967; from Kramer, 1983.)

Figure 6.5 shows the relationship between the different kinds of **available** and **unavailable water** for plants in different textured soils. Note that gravitational water in macro-pores is available to plants but is present for such a short time (24-48 hours) that for practical purposes it is not available. Figure 5.20 (Brady and Weil, 1999) shows the difference in the rate of water movement in two different textured soils. Figure 6.4 shows the relationships of the different kinds of water and plant roots.

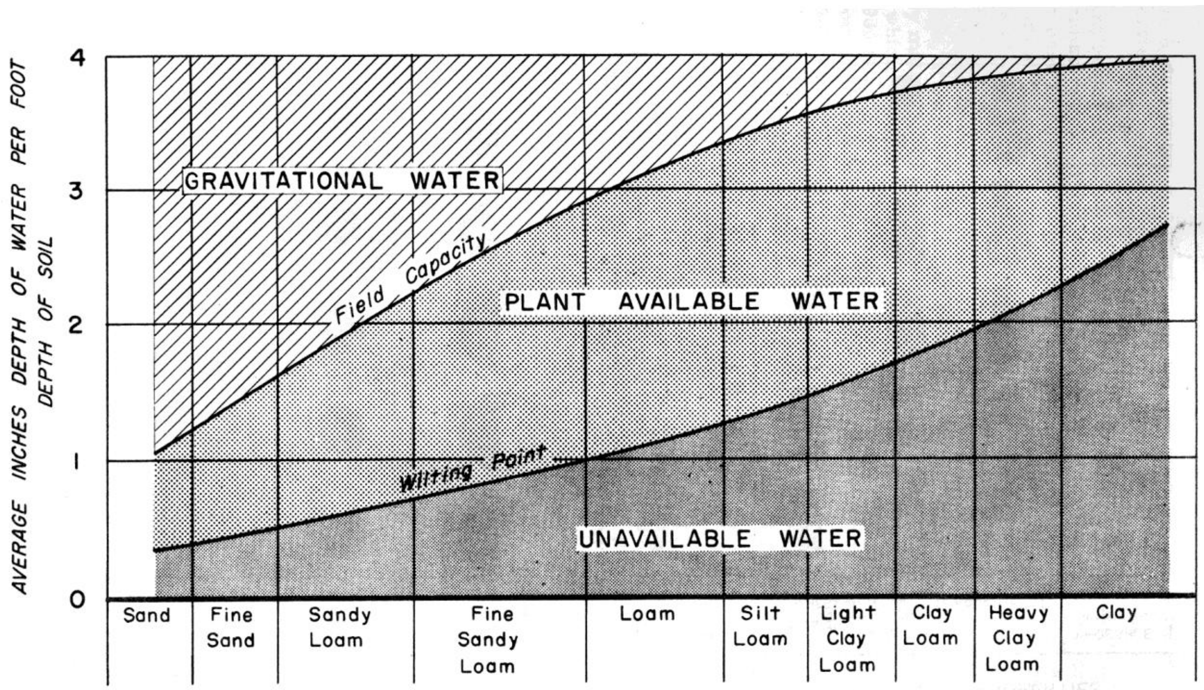


Figure 6.5.--Typical water characteristics of different-textured soils.

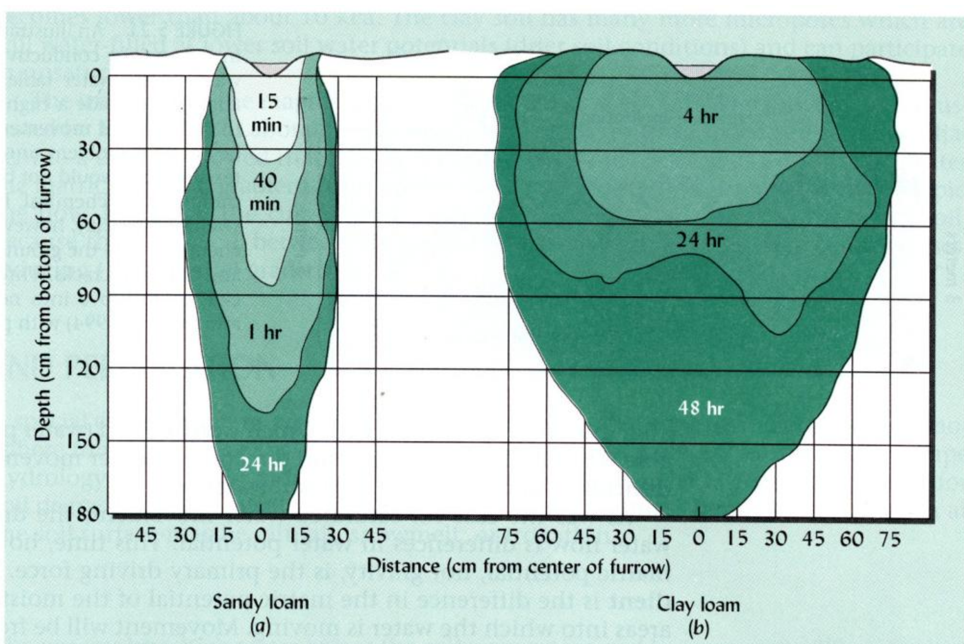


FIGURE 5.20 Comparative rates of irrigation water movement into a sandy loam and a clay loam. Note the much more rapid rate of movement in the sandy loam, especially in a downward direction. [Redrawn from Cooney and Peterson (1955)]

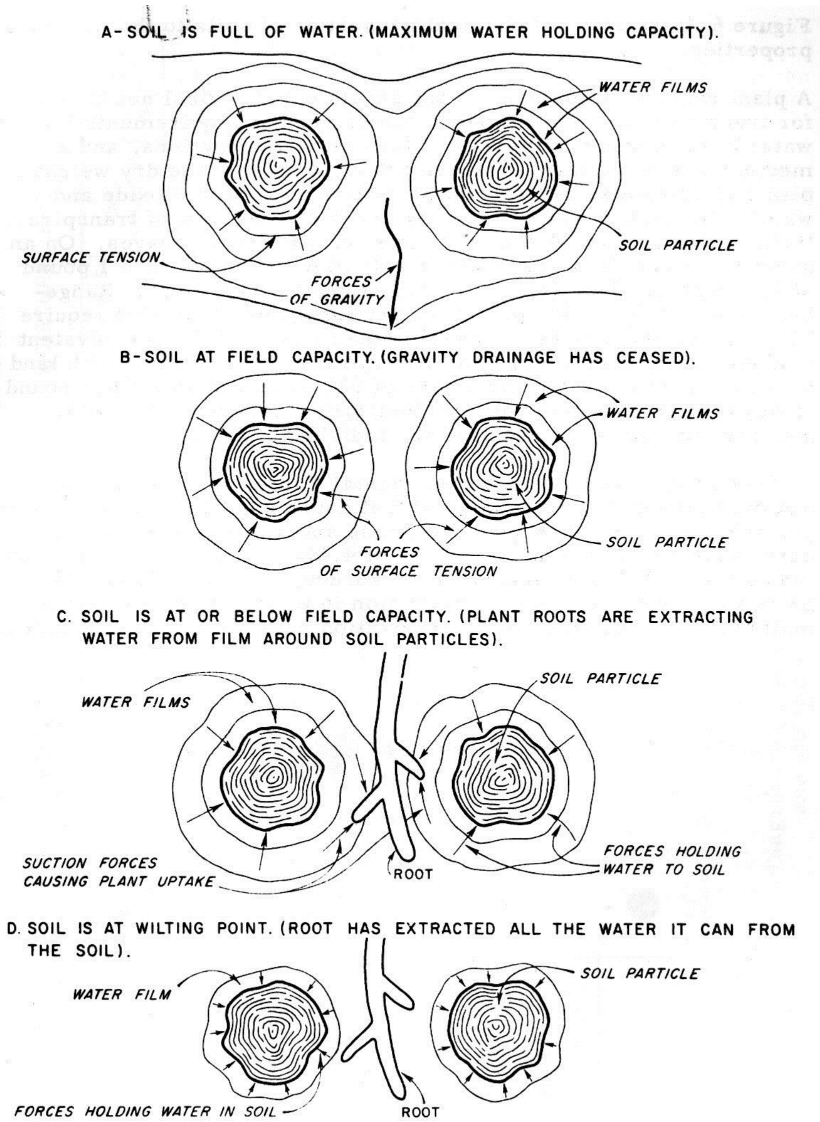


Figure 6.4.--Schematic diagrams of soil-moisture relationships.

Soil and plants play a major role in the **hydrologic cycle** of a landscape or watershed. Native plant communities annually transpire about two-thirds of the precipitation that falls on a watershed. In a native prairie for forest watershed most of the precipitation infiltrates into the soil where it is stored before being taken up by plants or released to streams as base flow. In intensively managed agricultural watersheds as much as 50-75% of the rainfall may not infiltrate but end up as surface runoff and stream storm flow. The surface runoff is responsible for large amounts of soil erosion carrying sediment to streams that then become clogged with both the sediments and the nutrients associated with the sediment. Figure 10 shows the complex paths of the hydrologic cycle and Figure 11 shows the impacts of land management on the major pathways of water as it moves through a watershed.

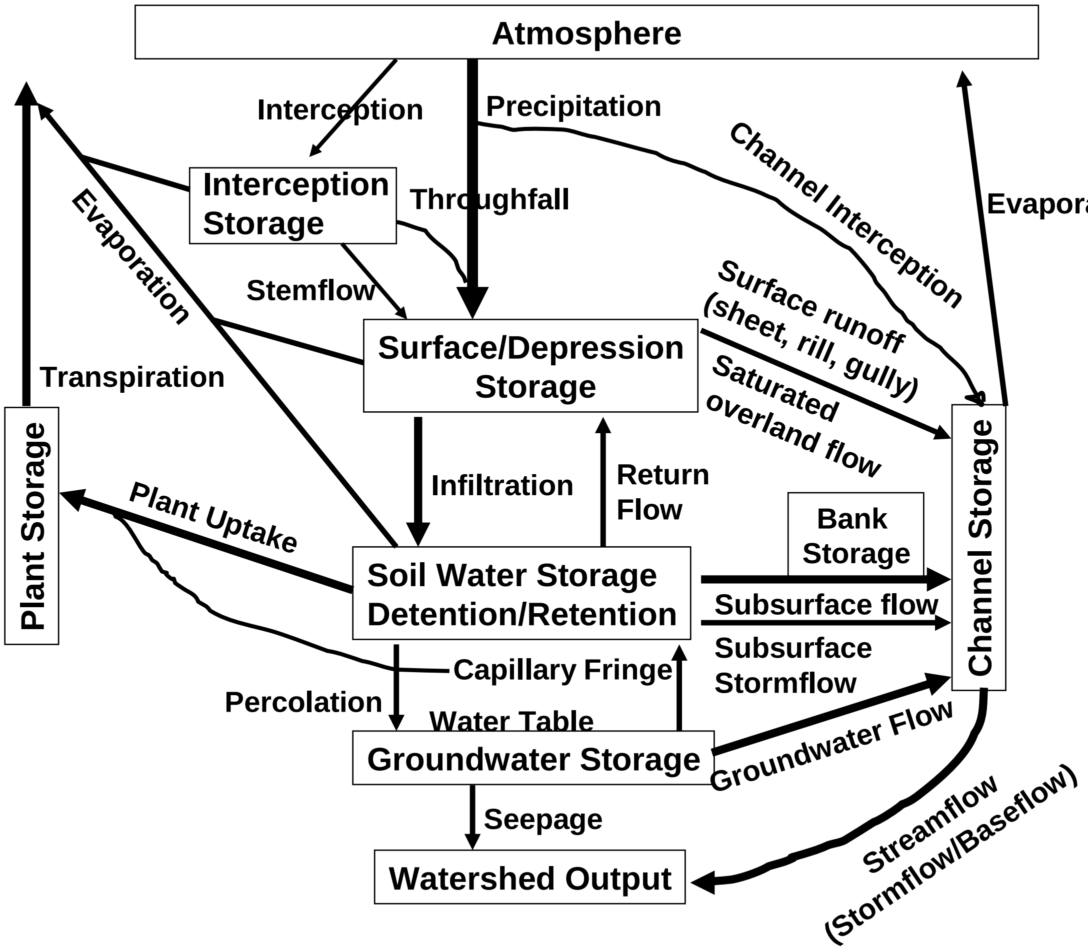


Figure 10. The hydrologic cycle showing the role of soil in storage and movement of water through a watershed. The rectangles represent the major water storage sinks in the watershed and the arrows indicate the major pathways of water from one sink to another.

The following definitions describe the various water storage sinks and pathways of water movement in a watershed.

Antecedent moisture - the amount of moisture in a storage unit before a precipitation or runoff event occurs.

Aquatard – a restrictive zone in the profile through which water cannot penetrate. This layer usually lies above the confined aquifer and water below the aquatard is under pressure giving rise to artesian wells if the aquatard is penetrated with a tube (water rises up the tube in response to the pressure below the aquatard).

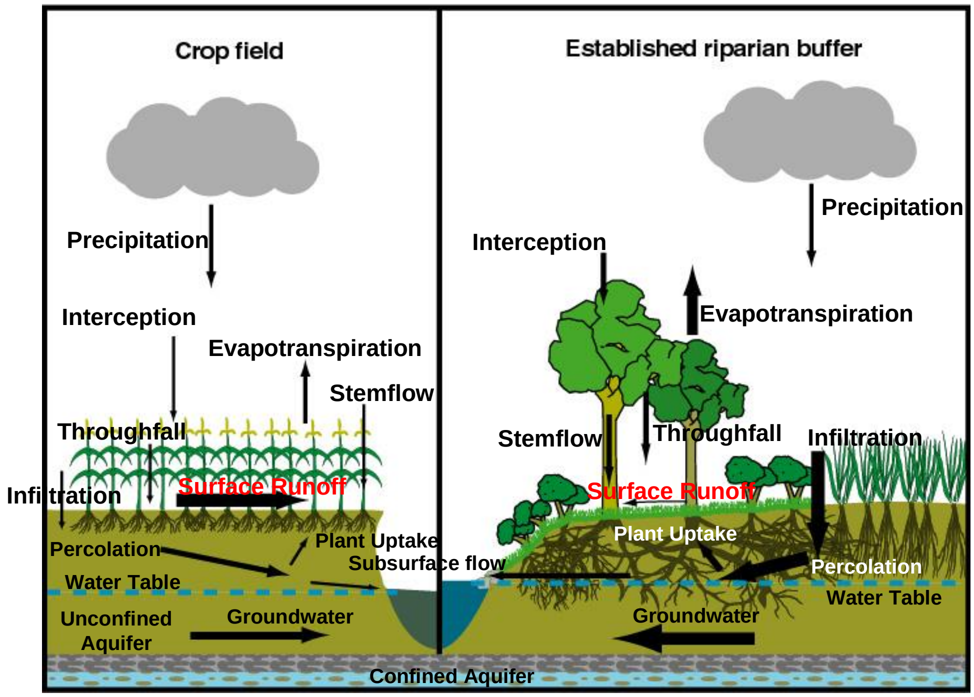


Figure 11. Water movement through two similar watersheds under different land-use management. Size of arrows indicate relative differences in volume of water movment.

Bank storage - water that is detained in the soil of the streambank.

Baseflow - the water which sustains streamflow between storm events or subfreezing periods. Base flow has two basic sources:

Bed load – the coarser material, usually mineral, moved along the bottom of streams.

Capillary fringe (rise) - the saturated zone above the water table held by capillary tension in the micropores.

Channel interception/precipitation - precipitation that falls directly into the stream channel. It becomes streamflow immediately.

Channel storage - the water contained in a segment of channel at any point in time. It not only is the water that is visible but also water stored in the streambed and the stream banks.

Confined aquifer – the saturated zone below an aquatard. Water in the confined aquifer is under pressure. The confined aquifer is usually isolated from the activities immediately above it. However, confined aquifers have recharge areas where the aquifer has contact with water from the surface which recharges the aquifer.

Depression storage - storage that occurs on any surface where water collects because there is no outlet for flow and remains there until it either seeps into the surface or evaporates.

Detention storage - water stored in the macro or noncapillary pores and which percolates through the soil in response to gravity. This water may flow fast enough through the pores to become part of stormflow if near the channel.

Dissolved load – all the organic and inorganic material carried in solution by moving water.

Erosion – the detachment and movement of soil particles creating sediment. Erosion processes are classified as rill, sheet and gully erosion.

Evaporation – loss of water as vapor from water surfaces such as streams, lakes, puddles, ponds and soil pores.

Groundwater – the water in an saturated zone or aquifer.

Groundwater flow - water that moves out of an underground reservoir of saturated material, the upper surface of which is called the water table. The material in which the groundwater is stored is called an aquifer. Some aquifers lie near the surface because of impermeable layers below them (perched water table).

Gully flow - water which moves in large depressions of the surface. A rill becomes a gully when you can no longer jump over it.

Hydrologic cycle – the movement of water between the land, streams, oceans and atmosphere. This cycle includes numerous pathways and major storage units such as the soil, oceans, atmosphere, and plants.

Infiltration - the process of water entering into the surface of the soil. It depends on surface soil conditions including soil texture, structure and organic matter content.

Interception - the process by which downward water movement, from precipitation, is interrupted and redistributed by whatever surface gets in the way of the precipitation.

Loess – wind-blown sediment dominated by grains in the silt size fraction.

Percolation - the process by which water moves through the lower horizons of the soil which often have different textures and structures than the surface horizon.

Precipitation - water that condenses into droplets or ice crystals and falls to the ground. Various forms include: rain, snow, hail, freezing rain, and fog drip.

Residence time - the length of time that water remains in one of the storage locations.

Retention storage - water stored in micro or capillary pores and which is held in these pores against gravity because of the cohesion (attraction between water molecules) and adhesion (attraction between water and soil particles) characteristics of water.

Return flow or exfiltration - water forced out of the ground by hydrostatic pressure to become part of surface runoff. Areas of return flow may occur along streambanks or as seeps.

Rill flow - water which moves in small depressions of the surface.

Saturation overland flow - surface runoff from seep areas or along streambanks where the soil is saturated. This differs from overland flow in that it has been in the soil profile and returned to the surface.

Sediment – detached soil particles that able to be transported and deposited.

Sheet flow - water which moves in thin sheets over large areas of the surface.

Soil water storage - water which is held in the pores of the soil. The distribution of pores depends on the texture (% clay, silt, and sand) and structure (the orientation of the clay, silt, and sand into units) of the soil which produces macropores (noncapillary pores) and micropores (capillary pores) through which water can move.

Stemflow - intercepted precipitation which runs down the trunk of a tree or the stem of any plant.

Storage - locations where water is temporally delayed and where evaporation may claim a portion of most of the detained water. Water is stored in the soil, on top of the soil in depressions or as snow, in vegetation and biological organisms, in puddles, lakes, and wetlands, in the atmosphere and in stream channels, even though it is in motion. We can envision the hydrologic cycle as water moving between a series of storage units. Frequently, the longer water stays in storage the less potential damage it can do.

Stormflow - water which appears in the channel in direct response to precipitation and/or snowmelt or channel interception.

Stream – a natural configuration in the land surface that transports water in perennial, intermittent, or ephemeral circumstances.

Streamflow - water in the stream channel originating from preciptitation and subsurface and overland flow that exits inot the stream channel.

Subsurface flow or interflow - water from rain or snowmelt that infiltrates the soil and moves through the unsaturated zone of the soil (percolates) above the water table.

Subsurface storm flow – subsurface flow from the variable source area that reaches the stream channel during a storm event.

Surface runoff or overland flow - water from precipitation or snowmelt that does not infiltrate the soil and flows over the surface as sheet flow, rill flow, or gully flow.

Suspended load – any material that is suspended in moving water.

Suspended sediment – particulate matter (organic or inorganic) that is suspended in and carried by water.

Throughfall - precipitation which may fall directly off the leaf or twig and join with drops that fall directly through the canopy.

Transpiration – loss of water as vapor from the stomates in leaves. This is water that has been extracted from the soil, passed through the plant and then lost from the leaves through stomatal pores.

Unconfined aquifer – an aquifer that is in contact with the surface. This aquifer is usually called the shallow groundwater and any activities above the aquifer can result in movement of materials into the aquifer.

Vadose zone (unstaturated zone) – zone in the soil above the water table where macropores are usually filled with air (not saturated). This zone is often synonymous with the rooting zone for plants.

Vegetation storage - water which accumulates on plant parts and may become part of throughfall, stemflow or be evaporated.

Watershed - any sloping surface that sheds water - a topographic divide that sheds water into two or more drainage basins.

Water table – the top of the saturated zone of the soil **–** below the water table almost all of the pores in the media are filled with water. Figure 5-13 shows the effect of water table depth on plant root development.

Action Items

Be prepared to discuss **soil water availability** in relation to soil porosity.

- Gravitational water
- Capillary water
- Field Capacity
- Permanent wilting point
- Hygroscopic water
- Available water

Be prepared to describe what drives water movement through plants.

What is the difference between matric, osmotic and gravitational water potential?

According to Figure 11.5 on page 267 of the textbook, which soil texture has the most available water for plant use?

What happens to available water as soil structure is destroyed?

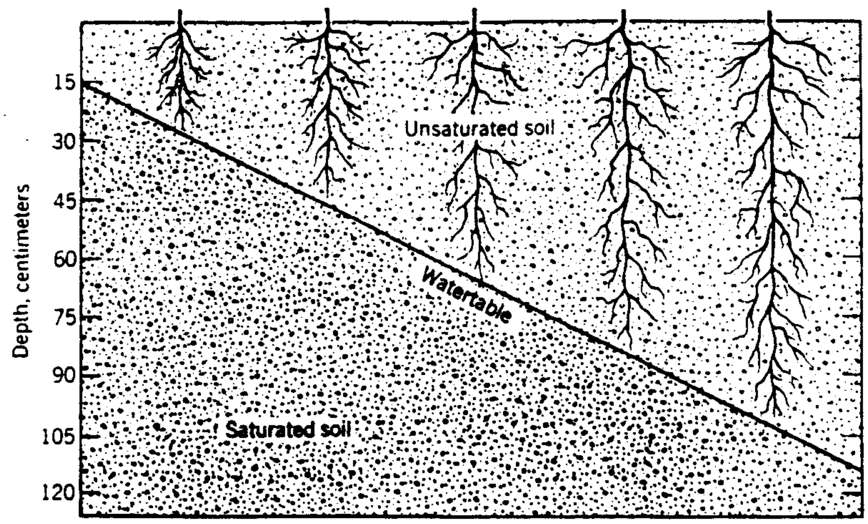


Fig. 5-13 The effect of depth to water table on the length of millet roots. Roots did not enter the saturated soil. (Based on data from Williamson et al., 1969.)

Soil fertility varies with many factors. All of the soil forming factors play a large role in controlling the fertility of a soil. Parent material provides the basis for the nutrient status of a site. Soils formed in granite are usually less fertile than ones formed in limestone. Soils formed in alluvium may be more fertile than those formed in glacial till. The thin A horizons of a forest soil and the top few feet of a prairie soil are usually the most fertile because they are in contact with the decomposing organic matter of the forest floor and feeder roots of the trees or, the deeper, annually dying, roots of the native prairie plants. In forest soil nutrients are leached from the E horizon down to the B horizon and in a prairie soil leaching of the deep A horizon also carries nutrients to the B. Any practice that reduces the organic matter content of the surface horizons reduces the fertility of the soil and increases the potential need for fertilization. Fertilizing trees is however, a tenuous issue at best. Nutrient requirements for mature trees of different species are not well known and because trees can exploit such a large volume of soil it is difficult to know how and where to apply fertilizers. Most of the feeder roots are located in the surface horizon and outside of the edge of the tree canopy. In most cases broadcast fertilization of lawn grasses provides sufficient fertilizers for most urban trees. Work with some plantation grown conifers in the south has led to the development of prescriptions that do result in tree growth responses.

Clay and humus play a major role in soil fertility because of their associated negative charges that attract and hold cations such as calcium (Ca^{++}) magnesium (Mg^{++}), potassium (K^{+}) and ammonium (NH^{-4}). The number of negative charges on clays or humus is referred to **cation exchange capacity** (CEC). **Exchangeable cations** are those that are attracted to the negative charges. **Base saturation** is expressed as the percent of base cations (non-hydrogen) that make up the total exchangeable cations - the percent of the CEC that is occupied by non-hydrogen cations. Base saturation is often related to soil pH. See Figure 7.21 (USDA Forest Service, 1961). In (b) you see a situation of low pH (very acid) and low base saturation because exchange sites are occupied by H^{+} ions. The H^{+} ions have displaced the base cations that either have been taken up by plants or leached from the soil system. In these ecosystems cation storage in the organic matter of the site become very important in maintaining the nutrient status of the site (living and dead plant and animal matter are the storehouse of nutrients).

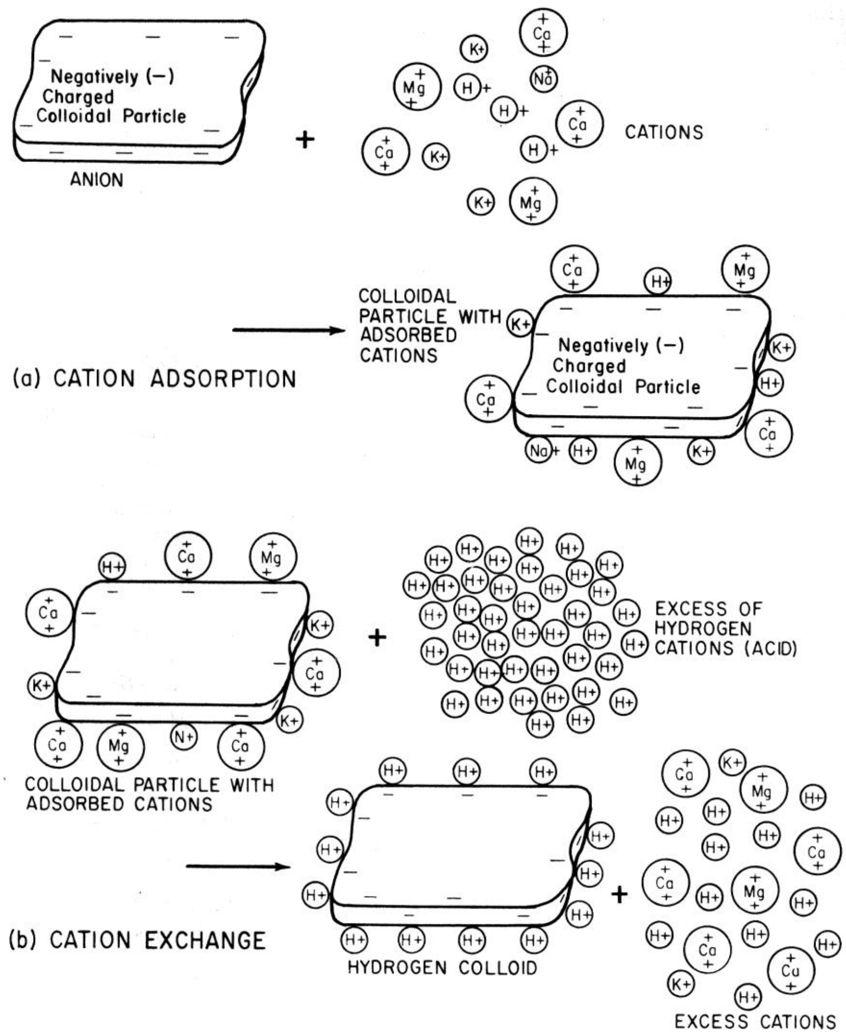


Figure 7.21.--Diagrammatic scheme showing (a) cation adsorption and (b) cation exchange.

pH of the soil can influence nutrient availability and microbial activity (figure 14.8). Note very carefully the differences in activity between bacteria, actinomycetes and fungi. In acid soils fungi are the dominant decomposers and the reduced diversity of organisms to carry on decomposition result in the accumulation of deeper and more complex O horizons. Also note the importance of pH on nutrient availability to plants. The macronutrients that are essential for plant growth are: H, C, O, N, K, Ca, Mg, P, and S (Tables 11.2 & 11.3 in text). The micronutrients essential for plant growth are: Cl, B, Fe, Mn, Zn, Cu and Mo.

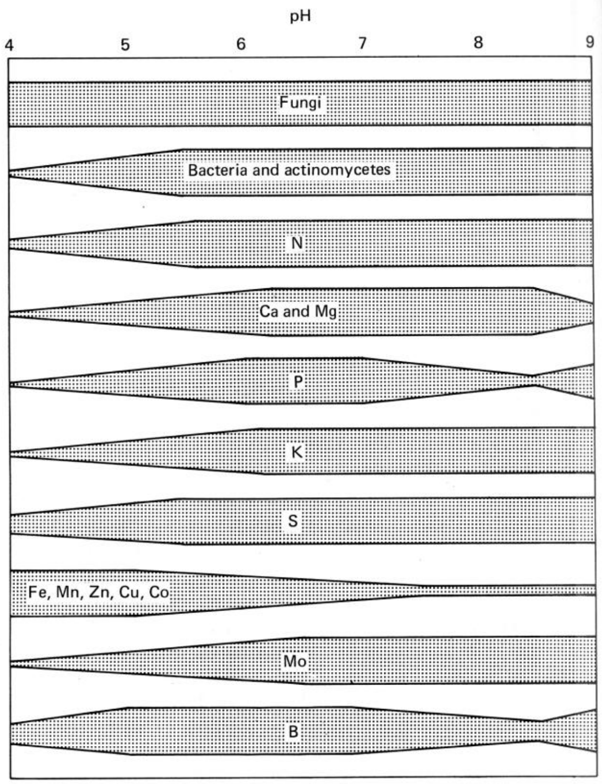


FIGURE 14:8. Relationships existing in mineral soils between pH on the one hand and the activity of microorganisms and the availability of plant nutrients on the other. The wide portions of the bands indicate the zones of greatest microbial activity and the most ready availability of nutrients. Considering the correlations as a whole, a pH range of approximately 6 to 7 seems to promote the most ready availability of plant nutrients. In short, if soil pH is suitably adjusted for phosphorus, other plant nutrients, if present in adequate amounts, will be satisfactorily available in most cases.

Action Items

1. What may happen to CEC in the surface layers of the soil as it is continually cultivated? Why?
2. What kind of forests (conifer vs deciduous) would you expect to have acid soils? Why? How would that influence the microbial activity in the soil? The decomposition of the organic matter?
3. Would you expect base saturation to be higher under a conifer stand than under a deciduous forest stand? Why?
4. What is the impact of pH on the availability of macro- and micro-nutrients?
5. What are the major sources of H, N & P in most terrestrial ecosystems?

6. C, H, and O are primarily taken up in what form by plants? These macro-nutrients make up about what percent of the mass of a leaf?
7. N, P, K, Ca and Mg are taken up in what forms by plants? About how much of the leaf mass consists of N, P, K and Ca?

Soil Biological Properties

Forest Floor - Recall that the O horizon is the organic horizon that lies above the mineral horizons. It can be divided into the O_i, O_e, O_a from top to bottom (Figure 1 in this handout). The following definitions apply:

- **Oi (L)** – contains recognizable plant and animal parts (leaves, twigs, needles, etc.), only slightly decomposed. Also referred to as the litter layer or the **L** layer by forest ecologists.
- **Oe (F)** – finely fragmented remains of the original material with much fiber evident, intermediate decomposition (still recognizable parts). This layer may be rich in fungal hyphae and fine roots that tie the material into a mat. Also called the fermentation layer or **F** layer by forest ecologists.
- **Oa (H)** – highly decomposed, smooth, amorphous material much of which is the remains of decomposition, processed through micro- and mesofauna. No recognizable parts left (exceptions may be pieces of bark or cones that are very resistant to decomposition). Also called the humus layer or **H** layer by forest ecologists.

These three layers are found in various combinations depending on the climate, pH and moisture of the soil, activity of soil fauna and nature of the plant material (Figure 10.12). The following three forest floors may be found:

- **Mor** – decomposition of litter is slow and incomplete resulting in the presence of all three layers usually with an abrupt transition between the O and the A horizons. In some cool, humid climates the contents of the H can be leached down into the mineral horizons, giving them their dark color. The F is usually very rich in fungal hyphae and often fine roots with little mixing activity from soil animals. Mor forest floors are characteristic of climates the inhibit decomposition, of plant species that produce slowly decomposing litter, and very infertile sites (often very acid). They can occur in any climate. These soils tend to be more acid with low base saturation (most conifer ecosystems).
- **Mull** – little or no Oi (L) for most of the year even though there may be large amounts of litter added in the fall. Oe (F) layer is often completely missing because decomposition is so rapid, so for most of the year the soil is covered with an Oa (H) layer which may be so intimately mixed with the A that an Ah may be designated. Often the upper layer of soil is completely covered by worm casts. The active mixing discourages the formation of fungal hyphae and the system is dominated by bacteria. The mull forest floor is characteristic of mild, moist climates and fertile soils that promote rapid decomposition. These soils tend to be more basic and have high base saturation (prairie and many deciduous forest ecosystems)
- **Moder** – these lie in between the mull and the moder. Often all three layers are present but the H may be very thin and shows a gradual transition into the A. There is usually more soil animals mixing so the F may not be as well defined either.

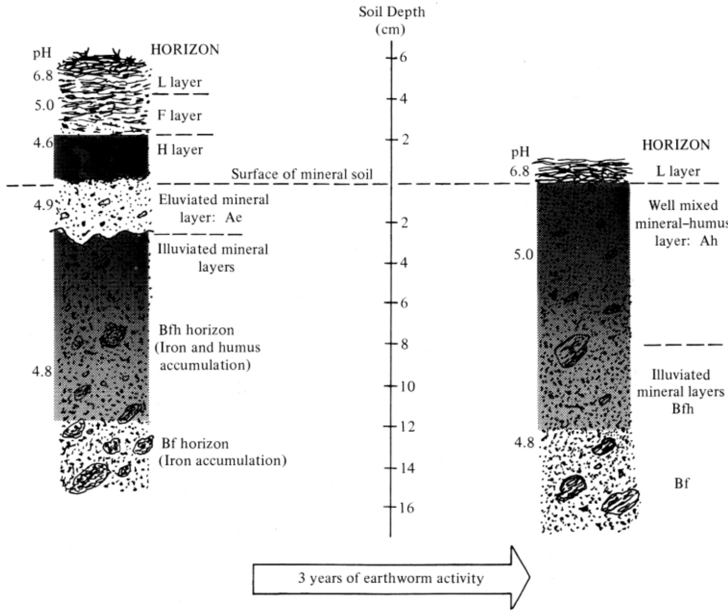


Figure 10.12. Conversion of a mor forest floor to a mull following the invasion of earthworms in a mixed conifer-hardwood stand. From Kimmins, J.P. 1987. Forest Ecology. MacMillan

Action Items

- Describe what kind of forest floors you might expect to find in Iowa forests. How might the floors differ if the forest is composed of mostly maples and basswood vs oaks and hickory? Why do you expect these differences?
- What kind of forest floor would you expect to find in the boreal forest of northern Canada or at high elevation forests in the Rockies? Why?
- Be prepared to use the vegetation map that we used at the beginning of the semester to assess the probable forest floors that would be found in each major ecoregion.

Soil organic matter plays many important roles in the formation and continued health of a soil. The plant and animal communities that live on and in the soil contribute and are responsible for processing this organic matter. Soil organic matter content can vary from 0% in very young soils to 80+% in histisols. Most soils lie between 0.5% and 5%. Annual temperature and moisture influence the plant communities and the amount of soil organic matter found across the US (Figure 6:8, Brady, 1974). (**IMPORTANT**: organic matter averages about 45% carbon).

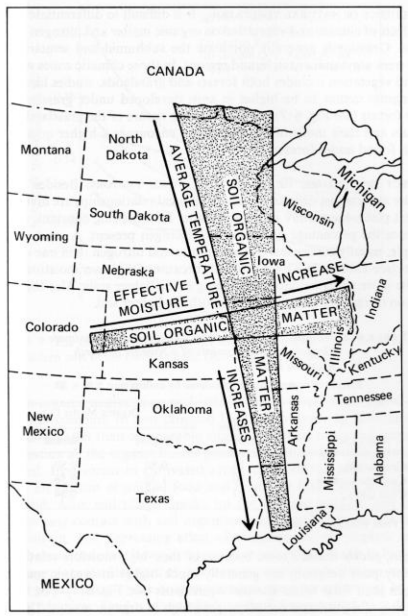


FIGURE 6:8. Influence of the average annual temperature and the effective moisture on the organic matter contents of grassland soils of the Midwest. Of course, the soils must be more or less comparable in all respects except for climatic differences. Note that the higher temperatures yield soils lower in organic matter. The effect of increasing moisture is exactly opposite, favoring a higher level of this constituent. These climatic influences affect forest soils in much the same way.

The following **six types of organic matter** are important to the soil (we will discuss several of these in detail):

1. **Living tissues** of plants and their microbial symbionts, including mycorrhizal fungi and their hyphae and nitrogen-fixing bacteria.
2. **Soil biomass –** living organisms in the soil that are not part of a plant including a wide variety of microbes, protozoa and invertebrates. Their total biomass in the soil may lie between 1-5% of the total soil organic matter but they are very important to the dynamics of soils and we will spend time addressing them. The invertebrate biomass (ants, beetles, earthworms, etc.) in a typical forest soil accounts for the largest amount of total animal biomass (squirrels, deer, etc.). (See discussion of Soil Organisms, below).
3. **Exudates and leachates –** biochemicals released by roots, mycorrhizal hyphae and microbes or leached from living or dead plant material. These include sugars, amino acids, enzymes, etc. that are the major source of energy of many soil organisms.
4. **Litter –** fresh or partially decomposed as discussed above. The litter material is often called the **light fraction** of the soil organic matter as it is easily decomposed. The **heavy fraction** is the humic material that is composed of hard to decompose material or products formed during decomposition that are also very resistant to further decomposition.
5. **Coarse woody debris** – dead wood larger than 2.5 cm (1 inch) in diameter. Dead logs are distinct islands within the mineral soil that act as a water reservoir and a site for intense biotic activity.
6. **Humus –** for the most part synthesized compounds released by microbes and invertebrates on decomposition of litter. Humus makes up 80-90% of the organic matter in most soils. It is responsible for the dark color in soils and is the long-term storage for CO_2 that plays a role in global warming. It is the most important part of soil carbon sequestration.

The typical composition of green plant tissue (leaves) is shown in the pie charts of Figure 12.2 (Brady & Weil, 1999). The rates of decomposition for the various components are listed below from rapid to very slow decomposition:

- Sugars, starches and simple proteins — rapid decomposition
- Crude proteins
- Hemicellulose
- Cellulose
- Fats, waxes, etc.
- Lignins and phenolic compounds — slow decomposition

When organic matter is added to aerobic soils, carbon compounds are: 1) biologically oxidized to produce carbon dioxide, water, energy and decomposer organism biomass, 2) nutrients are released (mineralized) from the OM, and 3) compounds resistant to microbial action are formed, either through modification of original material or microbial synthesis of new material (worm poop).

Figure 6:3 (Brady, 1974) shows the general changes that take place when fresh organic matter is added to the soil. Please read the caption carefully. We will look more specifically at the microorganism and invertebrate role in decomposition later.

Carbon/Nitrogen Ratio - About 42% of the dry weight of plant material is carbon. In soil organic matter that percentage is a bit higher (45%). The amount of N is much lower from less than 1 to 4%. Since N is the most universally limiting nutrient in ecosystems it stands to reason that the C/N ratio is important in determining the rate of decomposition. When fresh litter is added to the ground there is intense competition for the available N. Soil microbes incorporate about 8 parts of C into their cells for every one part of N (C/N = 8:1). Since about 2/3 of the C they ingest goes to respiration they need to ingest about 24 parts of C to get the 8 needed for cell building (need C/N = 24:1 in their food). This becomes very important for soil solution N. If residues with C/N of more than 24:1 are added to the soil, microbes need to scavenge the soil solution to find enough N (nitrate) to handle the additional C. By using that additional N there is less available for plant uptake and an N deficiency can result. The other important point is that the rate of decay of organic matter with a high C/N ratio can be delayed if there is not enough N available to support the microbial population.

Some typical C/N ratios are: spruce sawdust = 600:1; hardwood sawdust 400:1; wheat straw = 80:1; corn stover = 57:1; bluegrass from fertilized lawn = 31:1; alfalfa hay = 25:1. So you see that most plant materials have higher than the magic 24:1 ratio requiring microbes to find additional N in the soil solution to bring about decomposition. Figure 6:5 (Brady, 1974) demonstrates the relationship of the C/N ratio to decomposition.

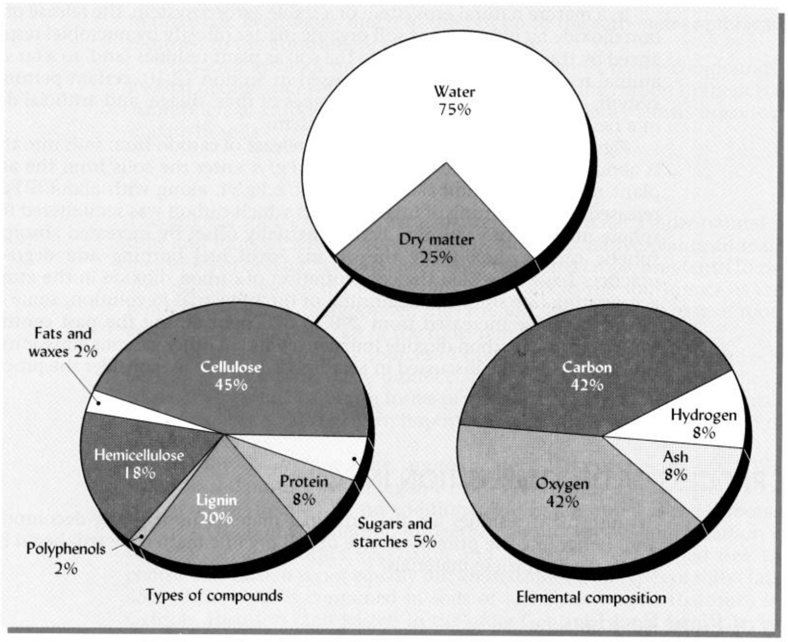


FIGURE 12.2 Composition of representative green-plant materials. The pie charts show typical composition. The major types of organic compounds are indicated at left and the elemental composition at right. The *ash* is considered to include all the constituent elements other than carbon, oxygen, and hydrogen (nitrogen, sulfur, calcium, etc.).

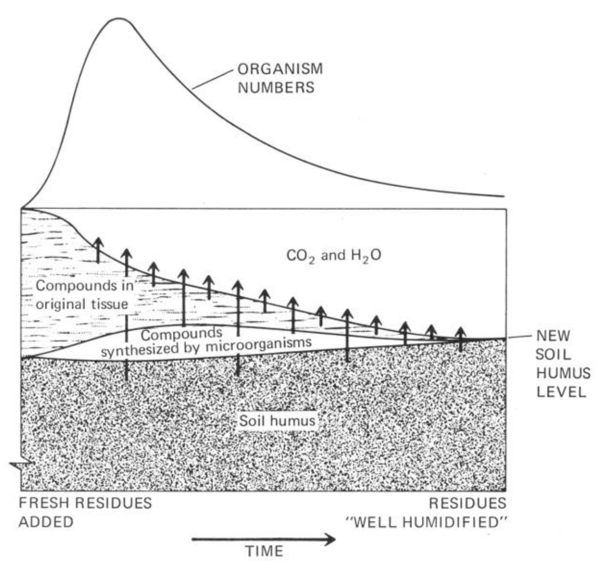


FIGURE 6:3. General changes in the chemical form of carbon- and hydrogen-containing compounds when plant residues are added to soil. Initially, organisms attack easily decomposable compounds such as sugars and celluloses, releasing CO_2 and H_2O and rapidly increasing their own numbers as well as the quantities of new compounds they synthesize. Note that as the initial organism buildup takes place, even the original soil organic matter is subject to some breakdown, CO_2 and H_2O probably being the decomposition products. As soon as the easily decomposed food is exhausted, microorganism numbers decline. The remaining microbes attack the more resistant compounds, both those in the original plant material and those that have been synthesized. In time, modified compounds from the original plant materials and new synthesized compounds, all of which are very slowly decomposed, become indistinguishable from the original soil humus. The time required for the process will depend upon the nature of both the residue and the soil.

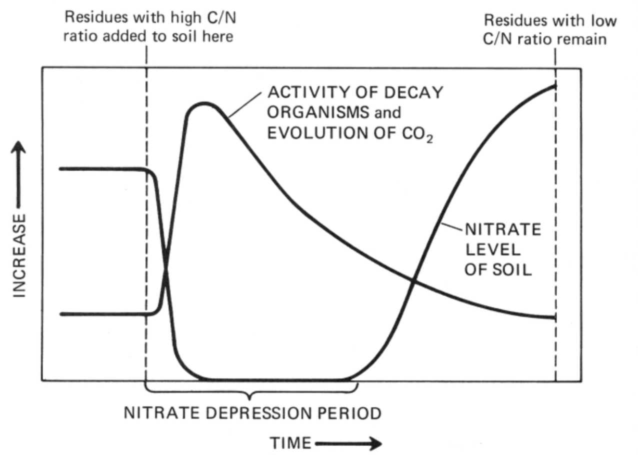


FIGURE 6:5. Cyclical relationship between the stage of decay of organic residues and the presence of nitrate nitrogen in soil. As long as the C/N ratio is wide, the general purpose decay organisms are dominant and the nitrifiers are more or less inactive. During the period of nitrate depression that results, higher plants can obtain but little nitrogen from the soil. The length of this period will depend upon a number of factors, of which the C/N ratio is of prime importance.

Soil Organisms - A complex food web of soil organisms exists in the soil just as it does above ground (Figure 11.2, Brady & Weil, 1999). Soil animals (fauna) come in many sizes: macrofauna such as moles, prairie dogs, earthworms, ants and millipedes to mesofauna such as tiny springtails and mites to microfauna such as nematodes and single-celled protozoans. Soil plants (flora) include roots of higher plants as well as microscopic algae and diatoms. Other microorganisms, too small to be seen without a microscope, include fungi, bacteria and actinomycetes. This group of microorganisms tends to predominate in terms of numbers, mass and metabolic activity. Their activity is measured by the amount of soil microbial biomass and soil respiration.

The sheer numbers of these organisms in the soil is mind-boggling. Under 1 m^2 of soil there may be more than 10^{10} each of bacteria, actinomycetes, fungi and algae. This may be translated into between 400-5,000 lbs/ac of bacteria, the same for actinomycetes, between 1,000-15,000 lbs/ac of fungi and lesser amounts of algae. Below 1 m^2 of soil there may also be >106 collembola, mites, nematodes and protozoa each and between 10-1,000 earthworms.

While the numbers are great and the weight per acre is impressive it must be remembered that these organisms are short lived and may go through many generations per year. The result is that their annual production may actually be 200-300 times greater than their average mass at any one time. Figure 11.10 (Brady & Weil, 1999) give some idea of the scale of size that the microorganisms are at in the soil.

Soil organisms are responsible for the **detrital food web** which is very important for the earth because if it did not exist we would be buried in “garbage” (organic matter of all kinds). As you have seen from Figure 6:3 many organisms are involved in the decomposition process. Some soil organisms are herbivores because they eat live plants. These include ants, some beetles and termites, mice, woodchucks, etc. For the most part the primary consumers of plant debris (detritus) are invertebrates such as beetles, maggots, termites, mites, collembola (springtails), nematodes, and earthworms. They produce fine particulate matter, feces, and their own dead bodies that are then fed on by secondary or tertiary consumers made up of microbes such as algae, fungi, bacteria, actinomycetes and protozoa. Remember that the algae, fungi, bacteria and actinomycetes are microflora and the rest of the organisms are either micro or mesofauna. The product of all of this action is carbon dioxide and water, mineral nutrients, soil humus (material resistant to decomposition) and energy.

Earthworms - Of the more than 3,000 species of earthworms worldwide, *Lumbricus terrestris* and *Allolobophora caliginosa* are the most common in Europe, and eastern and central US. *Lumbricus terrestris* is not native to the US but was brought over by Europeans and has been very successful almost too successful. These worms may eat 2-30 times their weight in a day and in the process create lots of burrows that young roots can easily penetrate. They produce large quantities of casts (poop) that is a mixture of soil, organic matter, bacteria and available nutrients. These casts also form stable soil aggregates that are further enhanced by extensive fungal hyphal activity. Earthworms are very sensitive to ammonia fertilizer, certain insecticides and tillage. Minimum tillage and animal manure favor their presence in agricultural landscapes. We say that they have been almost too successful because their voracious appetite and their large numbers in temperate hardwood forests severely reduces the longevity of a protective O horizon. If you walk through the woods and look carefully at the forest floor you will see many bare spots and in those spots you will see clumps of leaves gathered together and pulled into a worm hole. Leaves with low C;N ratios are processed rapidly leaving the soil bare and prone to more raindrop impact and more surface runoff resulting in soil erosion.

Termites - There are over 2,000 species of termites in the world with most of them concentrated in the grasslands and forests of tropical and subtropical regions of the world (termites are present in significant numbers in the southeastern US). The impact of termites is not as positive on the soil because as social organisms they build nests and mounds and as a result concentrate the organic matter in small areas rather than across a larger area. Similarly **ants** are social organisms and build nests and mounds in native prairies of central Iowa. Where these animals are active large quantities of soil turnover and mixing occur.

Nematodes are unsegmented round worms that are not visible to the naked eye and swim in water filled pores. When the pores dry they enter a resting phase in which they are immune from the environment. They are primarily predators on many kinds of microbes as well as plants.

Protozoa are single-celled mobile organisms that also swim in water filled pores in films of water. They are smaller than nematodes but larger than bacteria. They include amoebas, ciliates and flagellates. They engulf their food and also form resting stages. They are primarily predators on bacteria and live in the rhizosphere of roots. Their main impact on organic matter decay and nutrient cycling is based on their effects on bacterial populations.

Soil algae have chlorophyll and can carry on photosynthesis. Many species are motile and swim in soil pore water. Most grow best under moist to wet conditions but some have adapted to dry conditions forming lichens with fungi (symbiotic) on bare rock. Some form algal crusts in deserts that help reduce evaporation and soil erosion but are very sensitive to trampling. Algae are divided into green and yellow-green algae and diatoms. Diatoms are numerous in neutral to alkaline, well drained soils that are rich in organic matter. There may be 1-10 billion algae per square meter. Algae provide substantial amounts of organic matter to soils and some excrete polysaccharides that help soil aggregation.

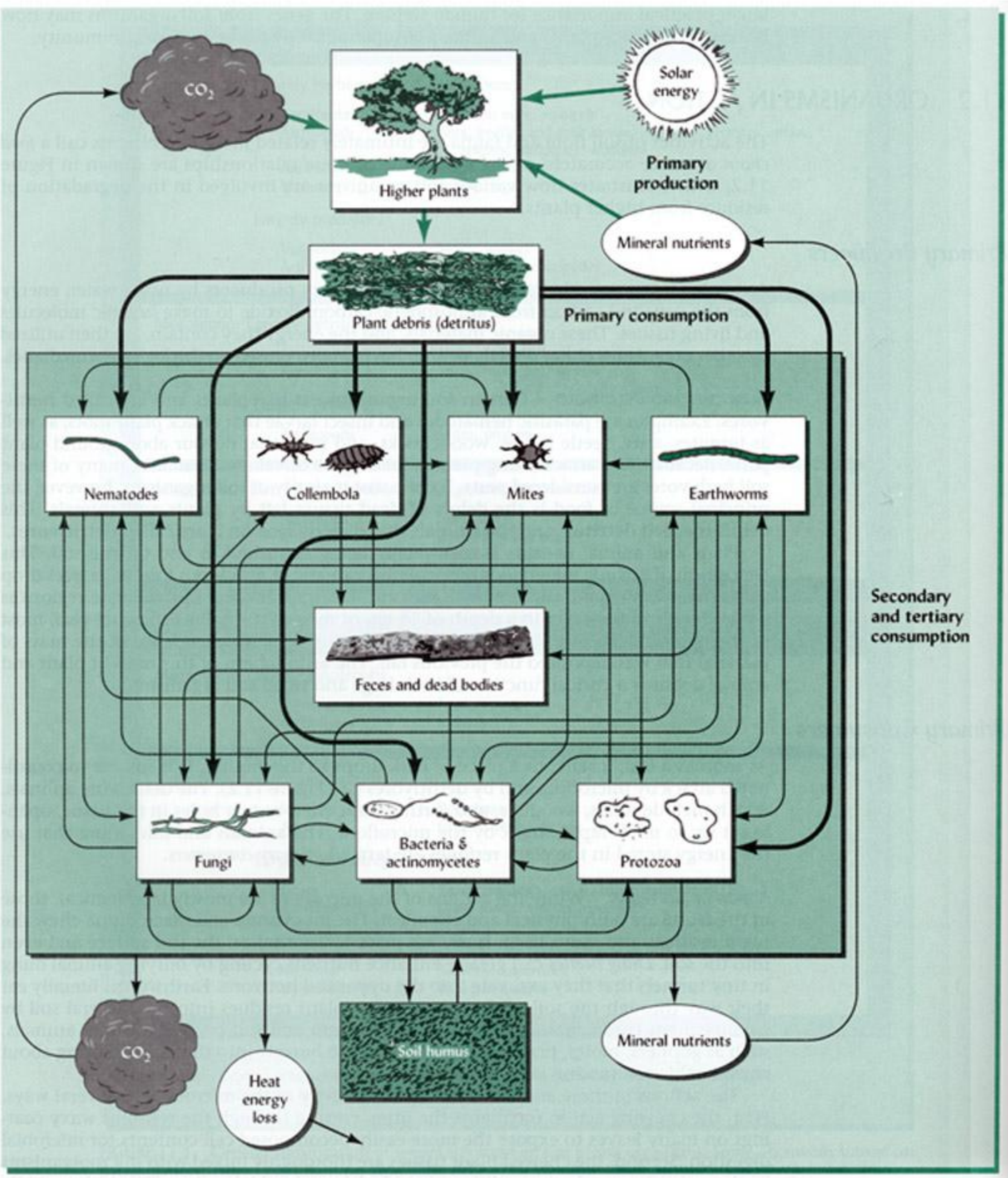


FIGURE 11.2 Greatly simplified diagram of the food web involved in the breakdown of higher-plant tissue. The boxes represent broad groups of organisms and pools of organic material, while the arrows represent transfers of carbon, energy, and nutrients between these pools. Because they capture carbon dioxide and energy, the higher plants are known as *primary producers*. Heavy arrows from the plant debris (detritus) to various organism groups represent *primary consumption*. The arrows within the large box represent *secondary* and *tertiary consumption*. Although all the groups shown play important roles in the process, the microorganisms represented by the lower three boxes account for 80 to 90% of the total metabolic activity. As a result of this metabolism, soil humus is synthesized, and carbon dioxide, heat energy, and mineral nutrients are released into the soil environment.

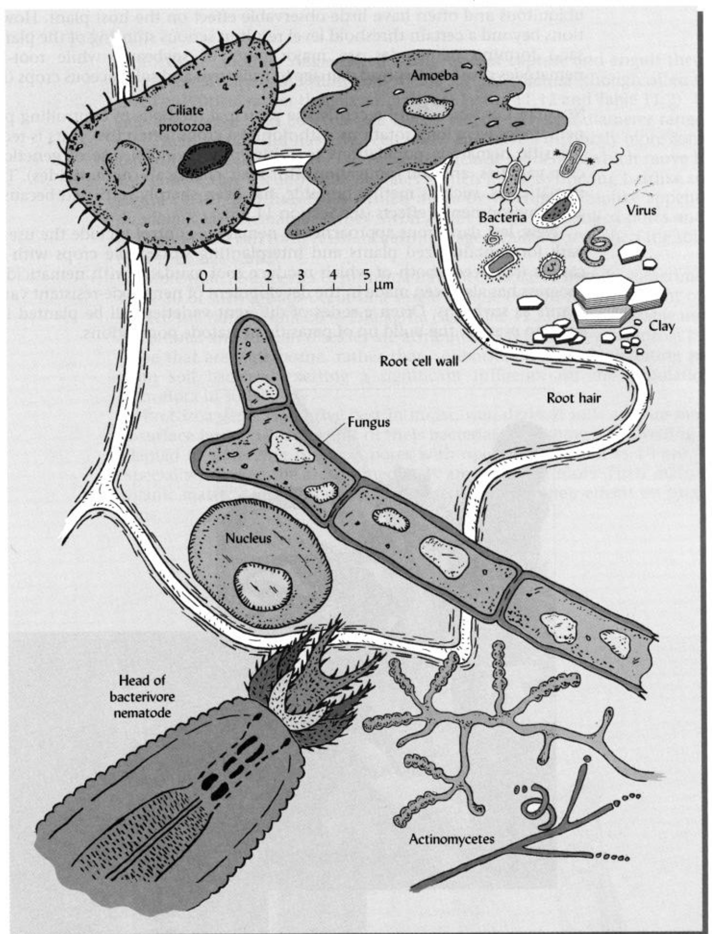


FIGURE 11.10 A depiction of representative groups of soil microorganisms, showing their relative sizes. (Drawing courtesy of R. Weil)

Figure 11.10. A depiction of representative groups of soil organisms, showing their relative sizes.

Soil actinomycetes are similar to fungi in that they have mycelia that are often very branched but are much smaller in diameter. They are like bacteria in that they have no nuclear membrane, are unicellular and often break up into spores. They live on decaying organic matter. They produce antibiotic compounds that kill other microbes (actinomycin, neomycin, streptomycin, etc). In forests they are important in that some species can fix atmospheric nitrogen into ammonium nitrogen that then becomes available to higher plants. They are responsible for the soil smell in soils with good humus contents. They are able to break down some of the most resistant compounds in the soil and usually are most important in later stages of decay. They are usually found in greatest numbers in soils between pH 6 and 7.5 and in those soils are outnumbered only by bacteria.

Soil bacteria are very small, single celled organisms with no distinct nucleus. They are found in three major forms, round (coccus), rod-like (bacillus) and spiral (spirillium). In soil, the rod-like ones dominate. A gram of soil may hold 20,000 different species of bacteria. They have adapted species that can live in all of the world's harshest environments. They include both autotrophic and heterotrophic species. Most are heterotrophic and live on easily decomposed materials. Almost all decomposition in wet soils is done by bacteria who are responsible for releasing methane and nitrous oxide into the air. They are involved in some of the most important soil organic and inorganic processes in the soil. They mediate the nitrification and denitrification processes in the nitrogen cycle for example. Cyanobacteria, previously called blue-green algae, contain chlorophyll and often live in wet soils where they can fix atmospheric nitrogen.

Plant roots are also very active in soil ecosystem processes. In this immediate discussion we will focus on the fine roots and especially the un-suberized growing root tips. Later we will review the structure and function of the larger root system of whole plants. In forests, especially conifer forests, there is more biomass turnover below ground in fine roots than in the leaves above ground even though about 75% of the biomass of trees is above ground (tree trunks & stems). In prairies as much as 75% of the total plant biomass may be below ground. In cultivated crops below ground biomass is equal to 15-40% of the above ground biomass. The 2 mm zone surrounding the roots and associated mycorrhizal hyphae are where the action is in the soil. This zone is called the **rhizosphere** and in it are found 10-50 times more bacteria and 5-10 times more fungi than in the bulk soil (Figure 11.13, Brady & Weil, 1999). This zone is enriched by exudates from the roots and by enzymes, hormones and other compounds from microbes. High-molecular weight compounds are excreted by root cap and epidermal cells producing a substance called **mucigel** that lubricates the root's movement through the soil, improves root contact with soil particles when the soil is dry and may protect it from certain toxic compounds. As much as 2-30% of the production of young plants may be devoted to excretions into the rhizosphere.

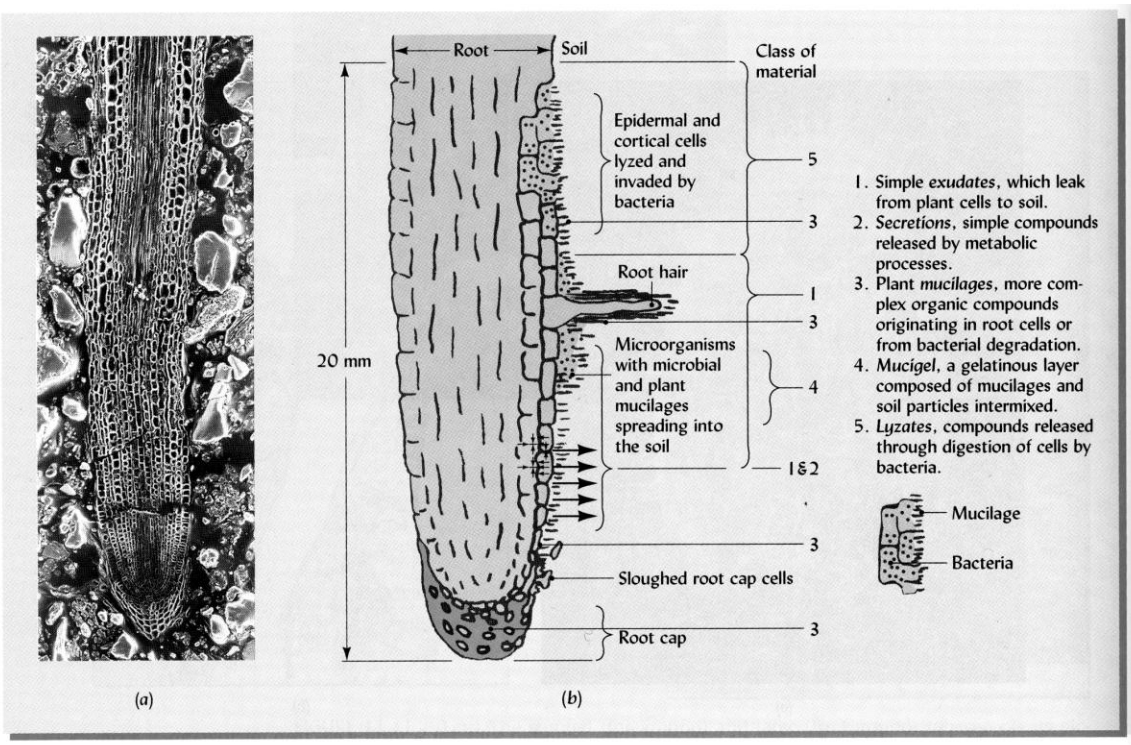


FIGURE 11.13 (*a*) Photograph of a root tip illustrating how roots penetrate soil and emphasizing the root cells through which nutrients and water move into and up the plant. (*b*) Diagram of a root showing the origins of organic materials in the rhizosphere. [(*a*) From Chino (1976), used with permission of Japanese Society of Soil Science and Plant Nutrition, Tokyo; (*b*) redrawn from Rovira, et al. (1979), used with permission of Academic Press, London]

Soil fungi are a very diverse group of organisms. Tens of thousands of species have been identified. Some believe there are still at least 1 million species in the soil waiting to be discovered. Their biomass ranges from 1,000 to 15,000 lbs/ac and in acid soils they are the most numerous microbes. There are three broad groups: 1) **yeasts**; 2) **molds**, and 3) **mushrooms**. Yeasts are single celled and live in waterlogged, anaerobic soils. Molds and mushrooms consist of long, branching chains of cells called **hyphae** that when twisted together are **mycelia**. These filamentous fungi reproduce by spores often in fruiting bodies. Molds are very important in decomposition in all kinds of soils and are the fungi that can tolerate low pH soils. *Pencillium*, *Fusarium* and *Aspergillus* are some of the most common molds found in the soil. Mushroom fungi are also extremely important in soils. They decompose woody and other complex materials and form symbiotic relationships with most higher plants. They convert up to 50% of the material they decompose into fungal tissue. The hyphae of fungi help develop soil aggregates and increase the surface area of plant root system with which they have a symbiotic relationship.

Certain fungi form symbiotic associations with higher plants called **mycorrhizae**. Mycorrhizae are the **symbiosis** of the combined fungi and root. The fungi are called **mycorrhizal fungi**. Most plants in the world develop these symbioses. The advantage for the fungi is that they have access to the sugars of the plant and in turn the plant "extends" its root system by 10-100 fold into soil pores that even it's root hairs might not get into. This increased surface area helps absorption of immobile and low concentration nutrients like P and others. They also help with water absorption. The mycorrhizae also help prevent the uptake of toxic metals in saline and acid soils. They also may produce antibiotics that help protect roots from pathogenic organisms. Two major kinds of mycorrhizae are formed (Figure 11.20, Brady & Weil, 1999).

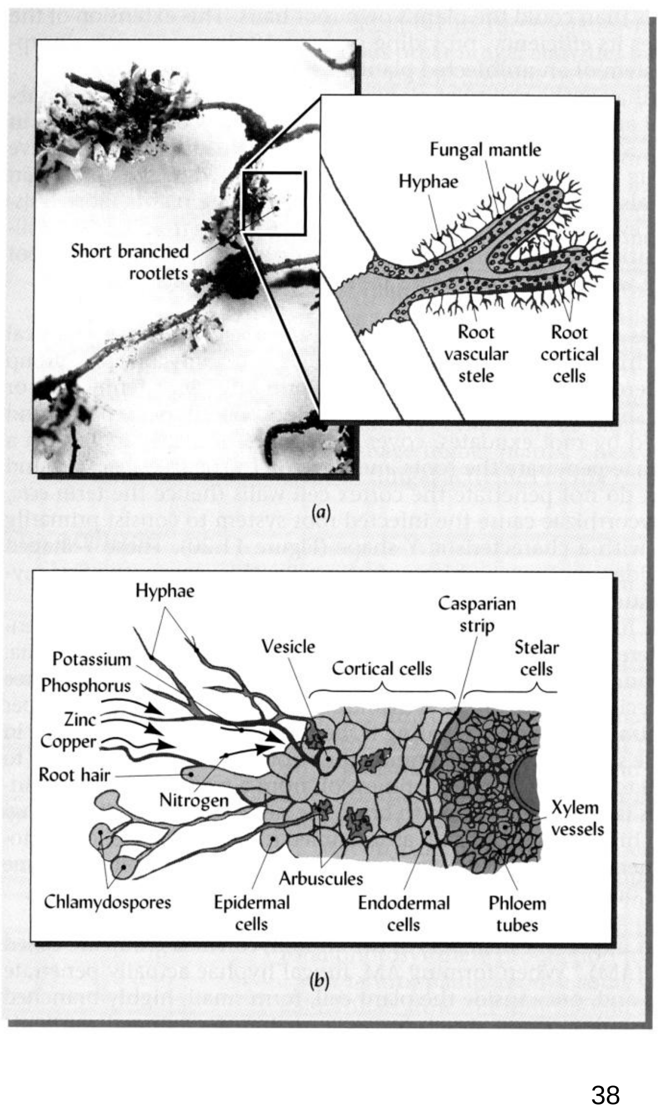


FIGURE 11.20 Diagram of ectomycorrhiza and arbuscular mycorrhiza (AM) association with plant roots. (*a*) The ectomycorrhiza association produces short branched rootlets that are covered with a fungal mantle, the hyphae of which extend out into the soil and between the plant cells but do not penetrate the cells. (*b*) In contrast, the AM fungi penetrate not only between cells but into certain cells as well. Within these cells, the fungi form structures known as *arbuscules* and *vesicles*. The former transfer nutrients to the plant, and the latter store these nutrients. In both types of association, the host plant provides sugars and other food for the fungi and receives in return essential mineral nutrients that the fungi absorb from the soil. [Redrawn from Menge (1981); Photo courtesy of R. Weil]

Ectomycorrhizae. Ectomycorrhizal infection is intiated from spores of hyphae in the rhizosphere of feeder roots. These propagules are stimulated by root exudates and grow vegetatively over the feeder root surface forming the external **fungal mantle** and often causing a deformation of the root tip. Following mantle development, hyphae develop intercellularly in the root cortex, forming the **Hartig-net** which may completely replace the middle lamellae between cortical cells. This Hartig-net is the major distinguishing feature of ectomycorrhizae. Ectomycorrhizae may appear as simple unforked roots, bifurcate, roots, multi-forked roots or even nodular-like roots that are readily visible to the naked eye. These visible structures are called "**short roots**". Each individual short root, regardless of branching pattern, is an ectomycorrhiza. Individual or numerous hyphae radiate from fungus mantles on short roots into the soil and eventually unite with the base of fruiting bodies. Over 2,100 species of ectomycorrhizal fungi have been identified on North American woody plants. Most fungi that form ecotymycorrhizae with forest trees are *Basidiomycetes*, which produce mushrooms or puffballs as reproductive structures. However, certain of the *Ascomycetes*, such as truffles, are also symbiotic. The fruiting bodies of these fungi produce millions of spores that are readily and widely disseminated by wind and water. Under normal forest conditions, many species of fungi are involved in the ectomycorrhizal associations of a forest, a single tree species, a single tree or even a small segment of lateral root. In fact, as many as three species of fungi have been isolated from an individual mycorrhiza. A single fungus species may also enter into ectomycorrhizal association with numerous tree species. Ectomycorrhizae occur naturally on many of the important tree species of the world. All members of the *Pinaceae*, i.e., *Pinus* (pine), *Picea* (spruce), *Abies* (fir), *Larix* (larch), *Tsuga* (hemlock), and *Pseudotsuga* (Douglas fir) as well as certain angiosperms such as *Salix* (willow), *Populus* (aspen), *Carya* (hickory and pecan), *Quercus* (oak) and *Fagus* (beech) are ectomycorrhizal.

Endomycorrhizae. The endomycorrhizal fungi, commonly referred to as the "**vesicular-arbuscular**" type (VA), are the most widespread and important root symbionts on the planet. They are not restricted to specific groups of plants, but occur in practically all families of angiosperms, gymnosperms, and many pteridophytes and bryophytes. Most of the economically important agronomic grain and forage crops, as well as the major commercial fruit and nut trees and berries, normally form endomycorrhizae. Many of our most important forest trees, such as *Liquidambar* (sweetgum), *Plantanus* (sycamore), *Ulumus* (elm), *Juglans* (walnut), *Fraxinus* (ash), *Populus* (cottonwood) and *Liriodendron* (yellow poplar) normally form VA mycorrhizae. Although endomycorrhizal fungi can form a loose network of hyphae on feeder root surfaces, they do not develop the dense fungal mantle found on ectomycorrhizae. Endomycorrhizal fungal hyphae penetrate the cell walls of the epidermis and then grow into the cortical cells of the roots, however, they do not penetrate the cell membrane. The infective hyphae may develop specialized absorbing or nutrient-exchanging structures called "**arbuscules**" in the cortical cells. Arbuscules consist of dense clusters of very fine dichotomously-branched filaments that may occupy the entire lumen of the cell. **Vesicles** are developed later, and appear as terminal swellings either within or between cells. Vesicles are thought to be storage tissue. No external morphological changes occur in roots infected with endomycorrhizal fungi. The fungi that form endomycorrhizae are mainly *Phycomycetes*. They do not produce large, above-ground fruiting bodies or wind-disseminated spores as do most ectomycorrhizal fungi. Some of them produce large azygospores or chlamydospores on or in roots, while others produce large sporocarps containing many spores. Spread of these fungi in soil is by root contact, moving water, insects or mammals. In the absence of a host, the spores of these fungi are able to survive for many years.

Action Item

An acre-furrow slice of soil is equivalent to one acre (43,560 sq ft), six inches deep and weighs 2 million pounds.

- Assume an organic matter content of 5%, how many tons of carbon are contained in the soil?
- Assume that 5% of the organic matter is soil biomass (living bacteria, fungi, and invertebrates). How many tons of microbial biomass are there?
- Assume 80% of the organic matter is humus. How much mass is there in humus?

- Why are coarse roots not included in the term soil organic matter?
- What does cultivation of soil do to the soil organic matter? Why?
- How might general forest soils and prairie soils differ in each of the organic matter types?
- Why is humus critical to water movement in the soil and to soil water quality and plant nutrient availability? This is an extremely important concept to understand so if you have problems with it please let me know. Think about the location and stability of humus and the properties that make it important for plant growth and water movement.
- Give examples of what each group can contribute to the soil ecosystem.
    - Algae
    - Fungi (mycorrhiza, plant pathogens, saprophytes)
    - Bacteria
    - Actinomycetes
    - Protozoa
    - How do their numbers differ between deciduous and conifer forests?
- What is the role of soil invertebrates, especially earth worms in decomposition and soil health?

Soil aggregation represents one of the major products of the intensive biological activity in soils. By now I hope you are sensitive to the high level of life that is present in the soil. It is this activity that differentiates a soil from dirt. If a soil is left in place to develop it can be viewed as a mixture of organo-mineral complexes known as **aggregates** and water- or gas-filled pores of different sizes and shapes. The aggregates and pores are very important to the health of the soil. Aggregates protect soil organic matter and help regulate the rate of decomposition. The organic matter tied up in aggregates helps retain nutrients from leaching and provides habitat for organisms. Aggregates have a hierarchical structure. That is **microaggregates** come together to form **macroaggregates**. Organic matter is the primary glue in both cases but different kinds of organic matter are active in the two different aggregate size classes. Aggregates have tremendous internal surface areas that are important for harboring the soil plant and animal community.

The stability of soil structure depends on the stability of the aggregates. Wetting and drying cycles test that stability. During drying cycles pores fill with gases that become trapped when water from above rewets the soil. As the water fills gas filled pores enough internal pressure may develop to break aggregates along planes of weakness (process called slaking). So stable aggregates must be bound firmly to resist the slaking.

Aggregation begins with the process of flocculation. Both clays and soil organic matter are colloidal in nature and have surface negative charges. Flocculation occurs when the negative charges between two of these particles are bridged by metallic cations such as iron, aluminum and calcium. Organic matter polymers can also bridge these particles. Many of these humic compounds are the products of root and fungal hyphae and bacterial exudation. These OM glues bind the primary silt, sand and flocculated clay particles and small organic fractions into the microaggegates. Microaggregates are often quite stable and can even resist the pressures of cultivation. However, they only contain micropores between them which restricts water movement in the profile.

Microaggregates are tied together by the continued activity of plant roots and fungal hyphae (Figure 4.26, Brady & Weil, 1999). These structures bind the microaggregates into larger macroaggregates that are relatively unstable to forces that break up the soil. Macroaggregates are also unstable if the plants or fungal activity decreases as may happen when plant communities come under the stress of environmental factors such as acid rain in the northeastern US. Finally, earthworms also can create macroaggregates as **casts** that are produced when the soil and organic matter are mixed as they pass through the gut of the worms.

Macroaggregate development begins again as soon as disturbed soils are repopulated by perennial plant communities. However, the rate of development may differ depending on the plants that make up the community and the rate at which their organic matter decomposes. A case in point are the buffer soils in which we work. Macroaggregate development is faster under cool-season grasses than under native prairie grasses because of the lower C/N ratio in the cool-season grasses and the longer life of their longer-lived roots.

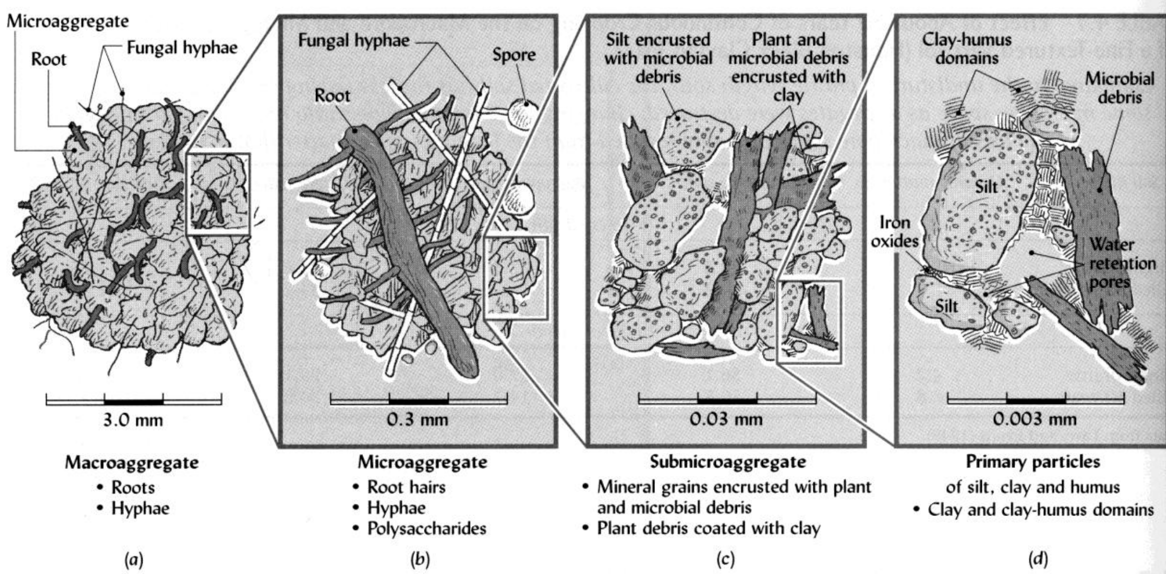


FIGURE 4.26 Larger aggregates are often composed of an agglomeration of smaller aggregates. This illustration shows four levels in this hierarchy of soil aggregates. The different factors important for aggregation at each level are indicated. (*a*) A *macroaggregate* composed of many microaggregates bound together mainly by a kind of sticky network formed from fungal hyphae and fine roots. (*b*) A *microaggregate* consisting mainly of fine sand grains and smaller clumps of silt grains, clay, and organic debris bound together by root hairs, fungal hyphae, and microbial gums. (*c*) A very small submicroaggregate consisting of fine silt particles encrusted with organic debris and tiny bits of plant and microbial debris (called *particulate organic matter*) encrusted with even smaller packets of clay, humus, and Fe or Al oxides. (*d*) Clusters of parallel and random clay platelets interacting with Fe or Al oxides and organic polymers at the smallest scale. These organoclay clusters or *domains* bind to the surfaces of humus particles and the smallest of mineral grains.

Action Items

- Be prepared to develop a model for soil aggregation and be able to discuss the importance of different kinds of organic matter in the development of aggregation.
- In addition to the vertical horizonation of soil and the horizontal variation associated with topography and geomorphology what other variations do you think occur in soils – think about the horizontal and vertical variation within the soil at the mesopattern (meter cubed or less) scale.
- Mesopatterns in Soils

    Soil logs

    - What determines the number of logs present in and on a soil?
    - What is the role of these logs in the forest ecosystem?
    - Would you expect to find more logs lying around in forests of the south or forests of the north? How about forests at lower elevations vs forests at higher elevations? What about conifer vs deciduous forests? How about redwood and western red cedar vs cottonwood?

    - Patterns associated with animals
        - What is the importance to soil development of burrows created by ants, worms, termites and burrowing rodents?
        - How do these burrows influence the movement quality of soil water as it moves through the profile?

- Patterns associated with plant species
    - Think of the patterns that can be created under different groups of plant species – the easiest to think about might be a mixed conifer hardwood stand.

Nutrient cycling is the result of all of the biological activity in a soil. Figure 19.1 (Barnes et al., 1998) shows the general flow of nutrients through an ecosystem. Natural ecosystems are said to be very conservative nutrient cycles because their losses from the ecosystem are few. The ecosystem tightly moves nutrients between the plant community and the soil with the help of the detrital food web. Losses from the ecosystem are balanced by the inputs from atmospheric deposition, mineral weathering and fixation. The specific nitrogen cycle is shown in Figure 8.62 (USDA Forest Service, 1961). This cycle is probably the most important in an ecosystem because of the mobility of nitrogen and the fact that natural inputs to an ecosystem depend on fixation and atmospheric deposition. The nutrient cycle can be subdivided into three sub-cycles – the geochemical cycle that accounts for the atmospheric and weathering inputs and losses from the system, the biogeochemical cycle which is the one we most commonly equate with the cycling of nutrients between the soil system and the plant and animal communities and the biochemical cycle that accounts for the annual redistribution of nutrients primarily in woody plants. Note the percentages of annual nutrient demands satisfied by the different cycles for some of the major nutrients (Figure 5.1, Kimmins, 199). Intensive agricultural management opens the nutrient cycle, especially the nitrogen cycle and losses outweigh the natural inputs requiring additions of nitrogen fertilizer. The “open” nature of agricultural nutrient cycles in the Midwest is responsible for the hypoxia problem in rivers and the Gulf of Mexico.

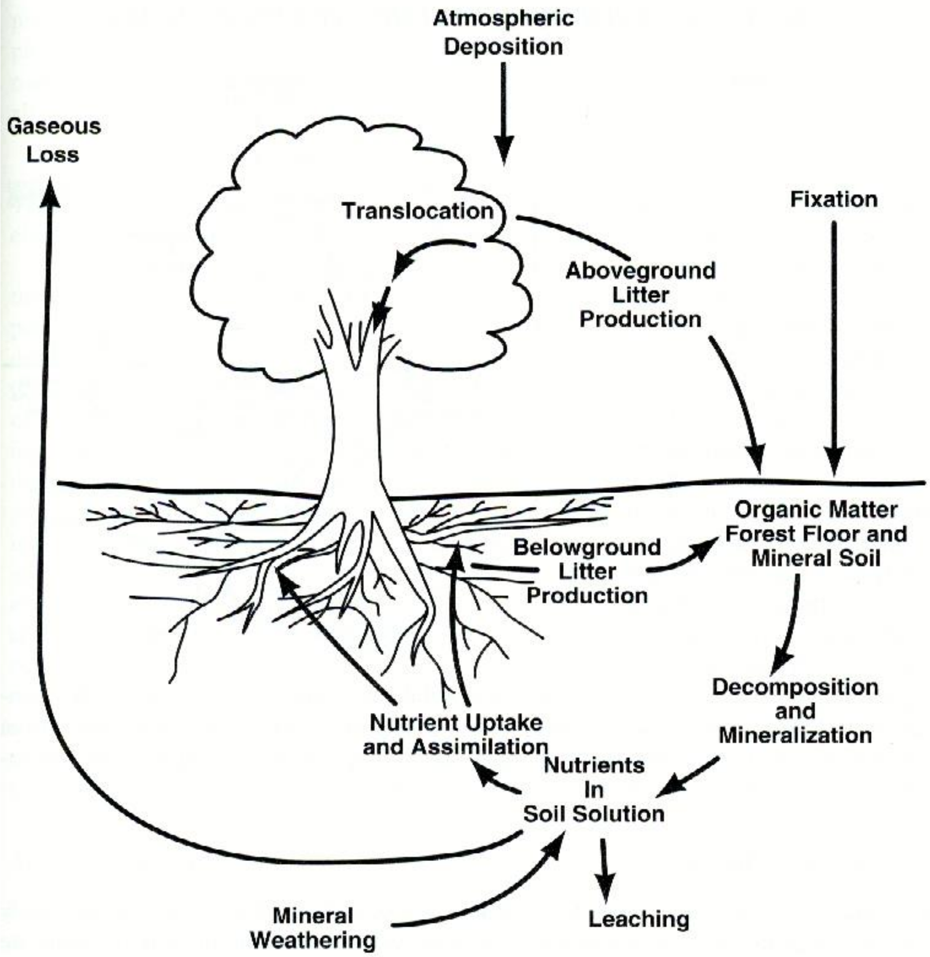


Figure 19.1. A conceptual diagram of the processes controlling the flow of nutrients into, within, and out of forest ecosystems. Nutrients enter forest ecosystems through atmospheric deposition, N_2 fixation, and mineral weathering. The flow of nutrients within forest ecosystems is controlled by nutrient uptake, the translocation of nutrients from senescent tissue, the return of nutrients in litter, the decomposition of litter on the forest floor and mineral soil, and the mineralization of nutrients from organic matter. Leaching and gaseous losses (i.e., denitrification) are processes by which nutrients are lost from forest ecosystems.

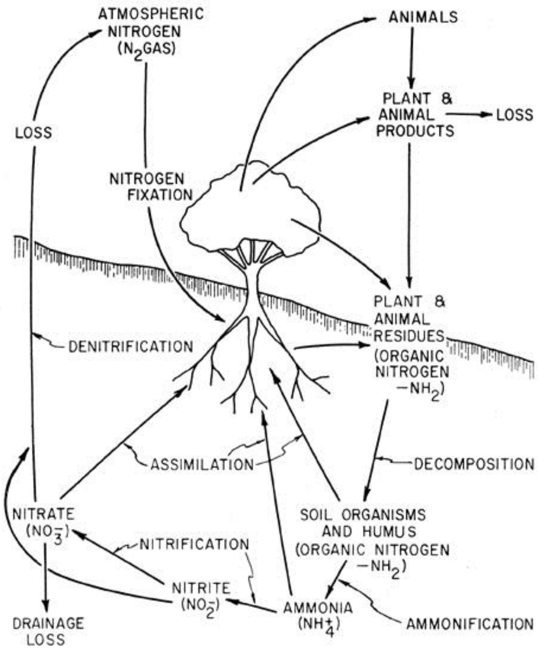
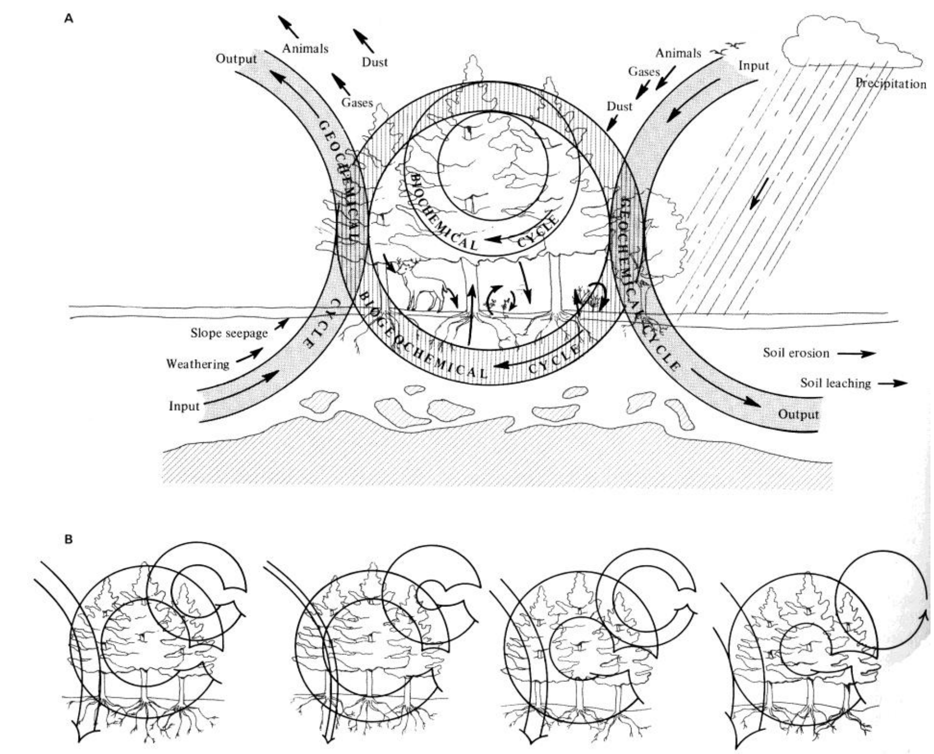


Figure 8.62.--The nitrogen cycle in soils.



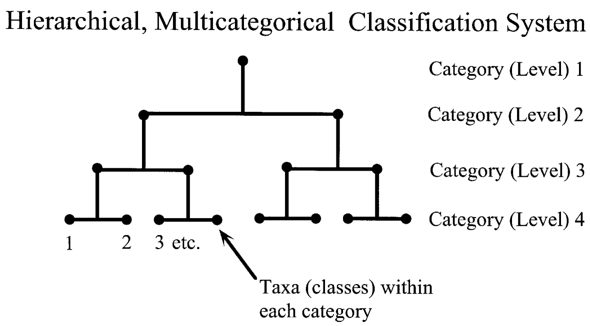
Cycle	Nitrogen	Phosphorus	Potassium	Calcium
Geochemical	16%	5%	12%	31%
Biogeochemical	45%	35%	66%	69%
Biochemical	39%	60%	22%	Trace

Figure 5.1

(A) The three major types of nutrient cycle: geochemical (between ecosystems), biogeochemical (within an ecosystem), and biochemical (within an organism; also referred to as internal cycling). (B) Percent of the nutrient dynamics in a forest ecosystem accounted for by the three cycles. The relative importance of the three cycles varies for different nutrients. Data for a 20-year-old loblolly pine plantation.

Soil Orders

Basic Structure of Soil Taxonomy and other Hierarchical Classifications

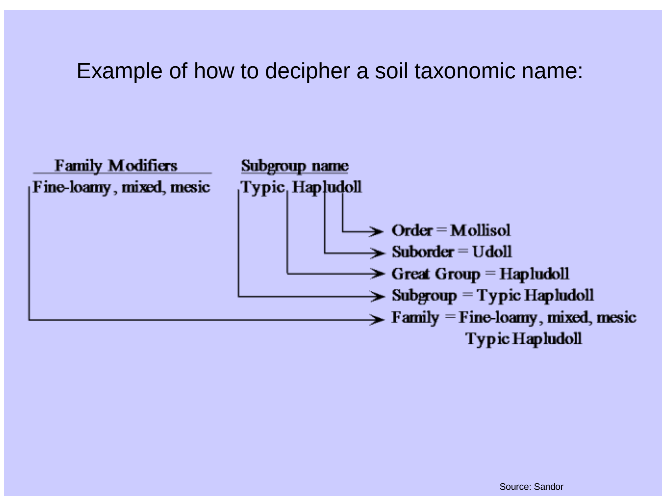


Categories and Classes of Soil Taxonomy

Category	Number of Classes (as of 2002)
Orders	12
Suborders	64
Great Groups	317
Subgroups	2,435
Families	8,062
Series	~22,000

Differentiating Characteristics – the criteria by which soils are grouped into different classes. Some major kinds in Soil Taxonomy are:

- Diagnostic horizons
    - Diagnostic surface horizons (epipedons)
    - Diagnostic subsurface horizons
- Soil moisture and temperature regimes
- Special chemical or mineral properties



Soil Classification

There are six categories in the Soil Taxonomy:

Order (11 taxa): This category is based largely on soil forming processes as indicated by the presence or absence of major diagnostic horizons. A given order includes soils whose properties suggest that they are not dissimilar in their genesis. They are thought to have been formed by the same general genetic processes.

Suborder (60 number od taxa): Suborders are subdivisions of orders that empasize gentic homogeneity . The presence or absence of properties associated with wetness, climatic environment, major parent material, and vegetation.

Great Group (approximate 303): Great groups are subdivisions of suborders according to similar kind, arrangement, and diagnostic horizons. The emphasis is on the presence or absence of specific diagnostic features, base status, soil temperature, and soil moisture regimes.

Subgroup (> 1,200): Subgroups are subdivisions of the great groups. The central concept of a great group makes up one group (Typic). Other subgroups may have characteristics that are intergrades between those of the central concept and those of the orders, suborders, or great groups. Extragradation is used to identify critical properties common in soils in several orders, suborders, and great groups.

Family: Families are sound in soils with a subgroup having similar physical and chemical properties affecting their response to management and especially to the penetration of plant roots. Differences in texture, mineralogy, temperature, and soil depth are bases for family differentiation.

Series (approximate 17,000 in the U.S.): Its differentiating characteristics are based primarily on the kind an arrangement of horizons, color, texture, structure, consistence, reaction of horizons, chemical, and mineralogical properties of the horizons.

Simplified Key to Soil Orders

Table 11.2.1. Formative elements of soil orders.

Soil Order	Derivation	Formative element
Alfisols	Nonsense symbol	alf
Andisols	Jap. *ando*, black soil	and
Aridisols	L. *aridus*, dry	id
Entisols	Nonsense symbol	ent
Gelisols	Gr. *gelid*, very cold	el
Histosols	Gr. *histos*, tissue	ist
Inceptisols	L. inceptum, beginning	ept
Mollisols	L. *mollis*, soft	oll
Oxisols	Fr. *oxide*, oxide	ox

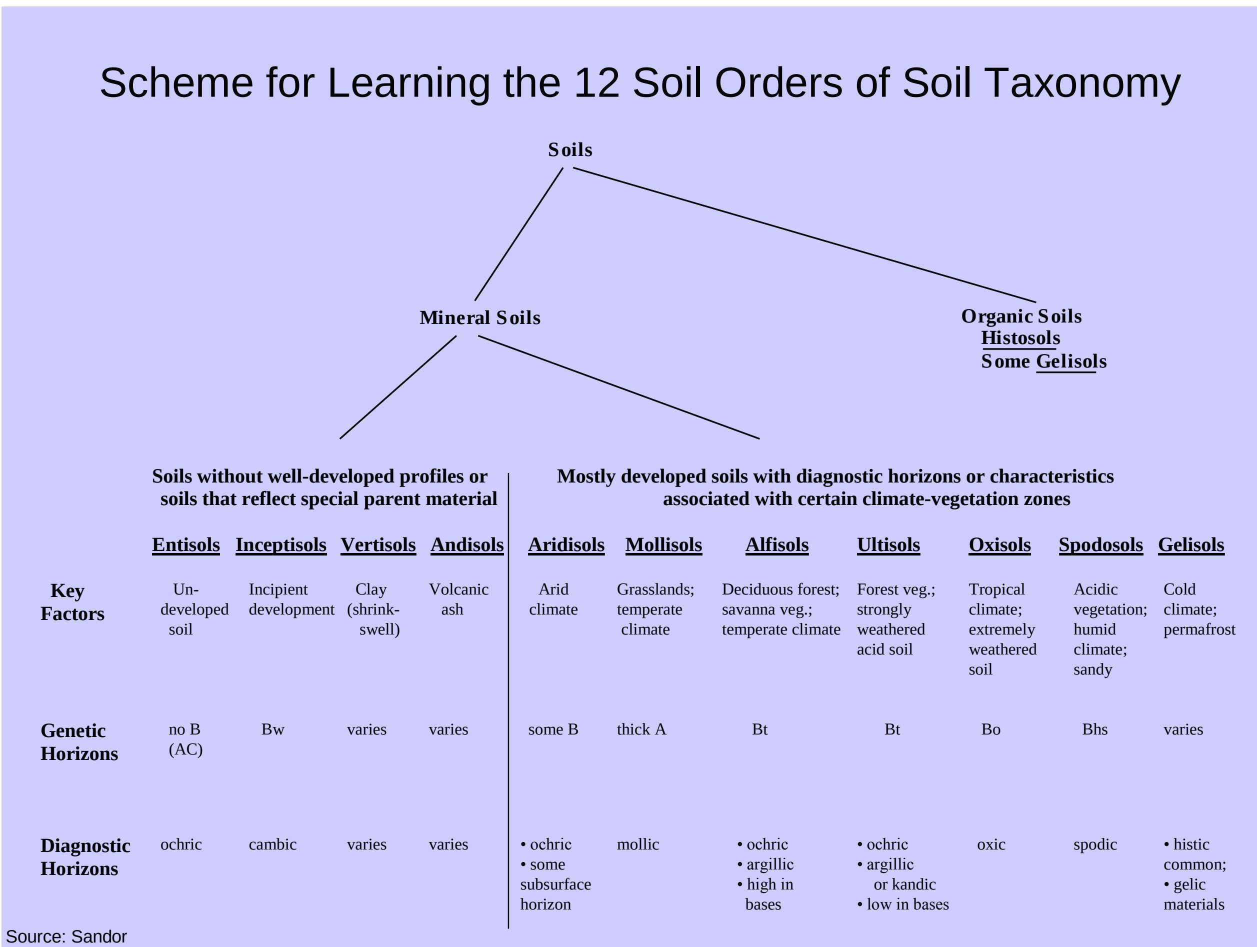
Spodosols	Gr. *Spodos*, wood ash	od
Ultisols	L. *ultimus*, last	ult
Vertisols	L. *verto*, turn	ert

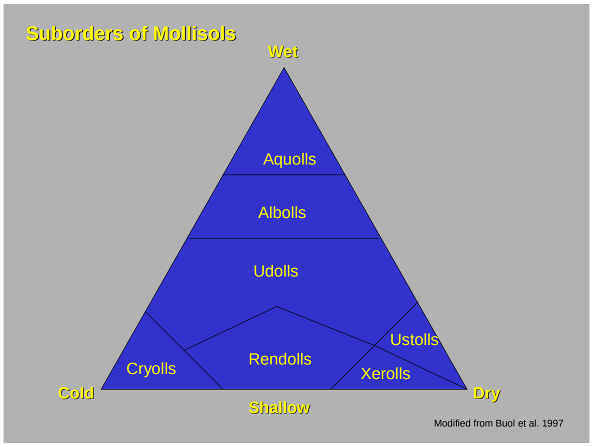
Table 11.2.2. Brief description of Soil Orders.

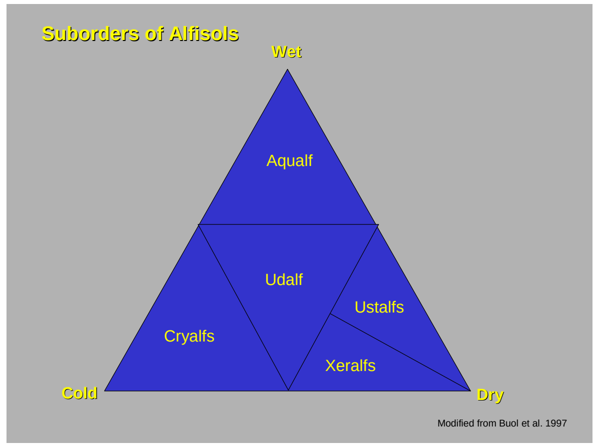
Soil Order	**General Features**
Alfisols	Alfisols develop in humid and subhumid climates, have average annual precipitation of 500-1300 mm. They are frequently under forest vegetation. Characteristic features: Clay accumulation in a Bt horizon, thick E horizon, available water much of the growing season, slightly to moderately acid.
Andisols	Andisols are soils with over 60 % volcanic ejecta (ash, cinder, pumice, basalt) with bulk densities below 900 kg/m^3. Characteristic features: Dark A horizon, early-stage secondary minerals (allophane, imogolite, ferrihydrite clays), high adsorption and immobilization of phosphorus, very high cation exchange capacitity.
Aridisols	Aridisols exist in dry climates. Charactersitic features: horizons of lime or gypsum accumulation, salty layers, and/or A and Bt horizons.
Entisols	Entisols have no profile development except a shallow marginal A horizon. Many recent river floodplains, volcanic ash deposits, unconsolidated deposits with horizons eroded away, and sands are Entisols.
Gelisols	
Histosols	Histosols are organic soils (peat and mucks) consisting of variable depths of accumulated plant remains in bogs, marshes, and swamps.
Inceptisols	Inceptisols, especially in humid regions, have weak to moderated horizon development. Horizon development have been retarded because of cold climated, waterloged soils, or lack of time for stronger development. Characteristic feature: Texture has to be finer than loamy very fine sand.
Mollisols	Mollisols are frequently under grassland, but with some broadleaf forest-covered soils. Characteristic features: Deep, dark A horizons, they may have B horizons and lime accumulation.
Oxisols	Oxisols are excessively weathered, whereas few original minerals are left unweathered. They develop only in tropical and subtropical climates. Characteristic features: Often Oxisols are over 3 m deep, have low fertility, have dominantely iron and aluminium clays, and are acid.
Spodosols	Spodosols are typically the sandy, leached soils of cood coniferous forests. Characteristic features: O horizons, strongly acid profiles, well-leached E horizons, Bh or Bs horizons of accumulated organic material plus iron and aluminium oxides.

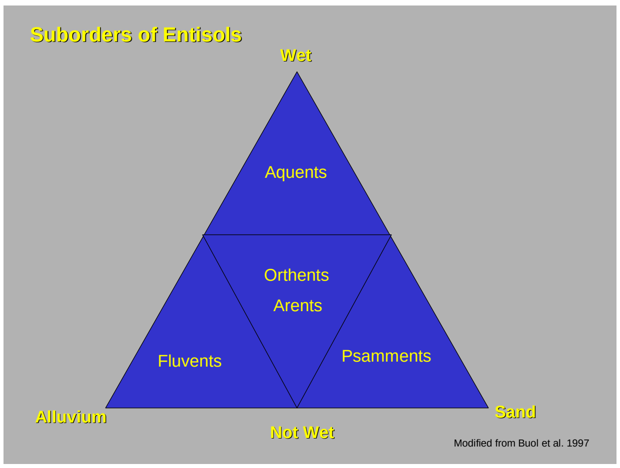
Ultisols	Ultisols are ectensively weathered soils of tropical and subtropical climates. Characteristic features: Thick A horizon, clay accumulation in a Bt, strongly acid.
Vertisols	Vertisols exist most in temperate to tropical climated with distinct wet and dry seasons. They have a high content of clays that swell when wetted and show cracks when dry. Characteristic features: Deep self-mixed A horizon , top soil falls into cracks seasonally, gradually mixing the soil to the depth of the cracking.

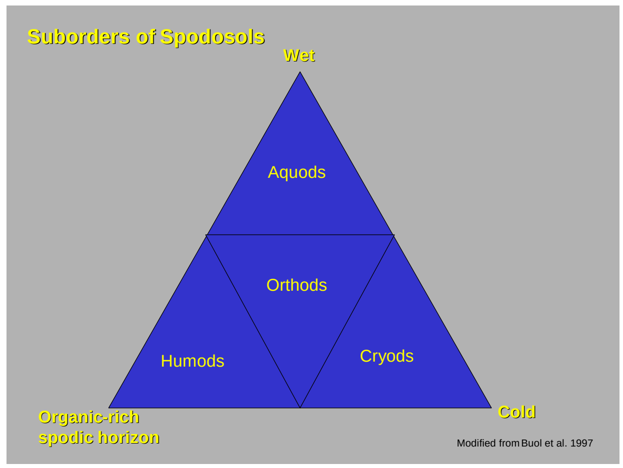
From McSweeney, Kevin 2006. Web Page Class Notes for Soil Morphology, Classification and Mapping, UW-Madison. (http://www.soils.wisc.edu/courses/SS325/soilscience325.html)

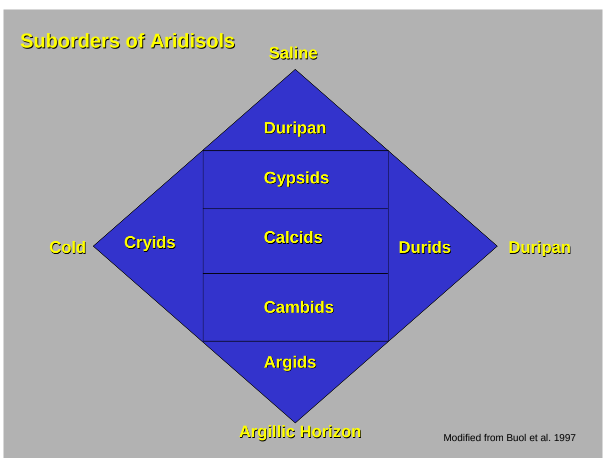



Suborders of Mollisols
Wet
Aquolls
Albolls
Udolls
Ustolls
Rendolls
Cryolls
Xerolls
Cold
Dry
Shallow
Modified from Buol et al. 1997

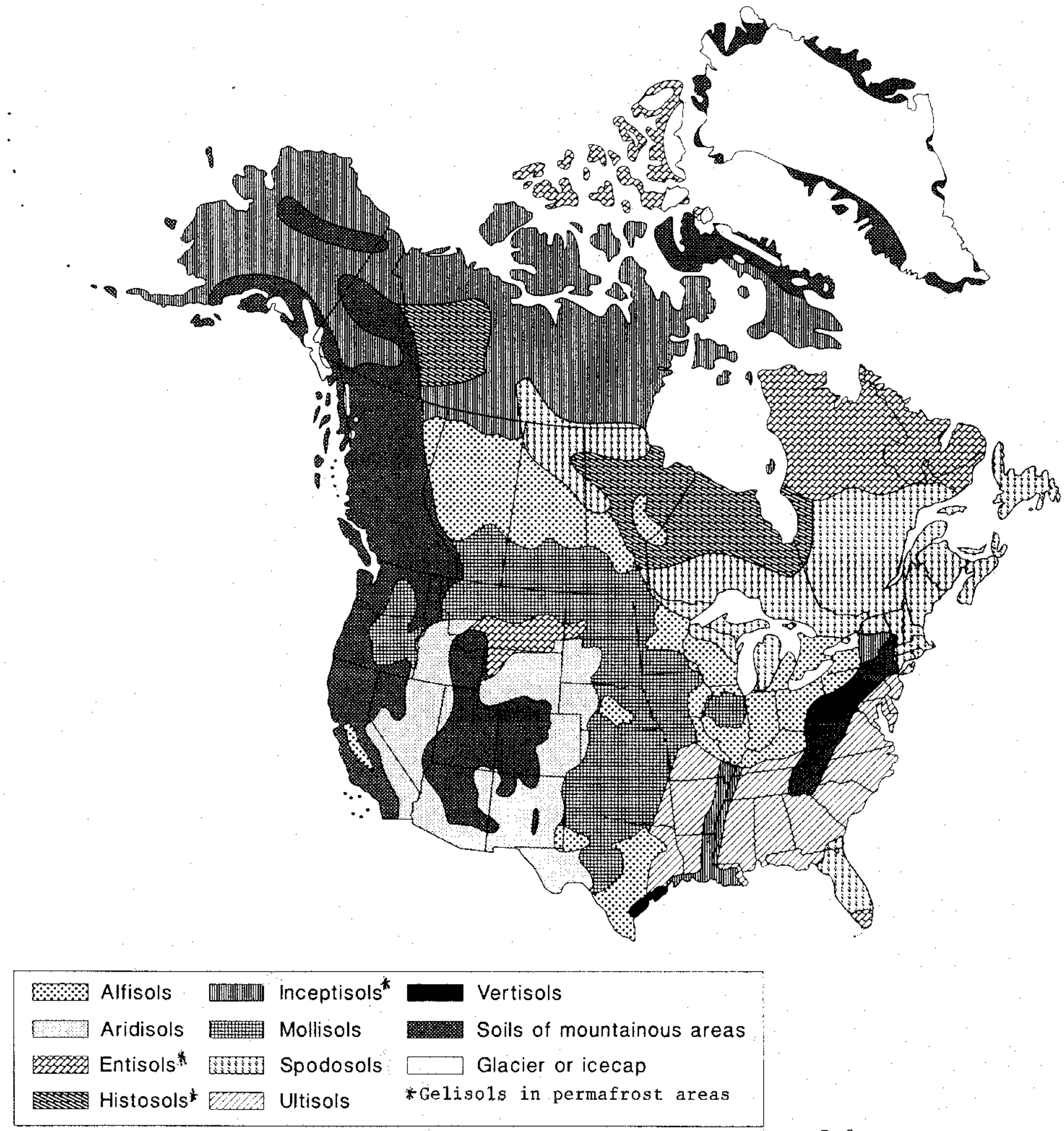

Suborders of Alfisols
Wet
Aqualf
Udalf
Ustalfs
Cryalfs
Xeralfs
Cold
Dry
Modified from Buol et al. 1997


Suborders of Entisols
Wet
Aquents
Orthents
Arents
Fluvents
Psamments
Alluvium
Sand
Not Wet
Modified from Buol et al. 1997


Suborders of Spodosols
Wet
Aquods
Orthods
Humods
Cryods
Organic-rich
spodic horizon
Cold
Modified from Buol et al. 1997


Suborders of Aridisols
Saline
Duripan
Gypsids
Cold
Cryids
Calcids
Durids
Duripan
Cambids
Argids
Argillic Horizon
Modified from Buol et al. 1997

Soil Map of USA and Canada



Reference:

FIGURE 2.2. Distribution map of the orders of soil of North America.

Flora of North America 1993

Biome relationships to soil orders

Soil Order	Biome (Vegetation)
Oxisol	Tropical evergreen/deciduous forests
Mollisols, Aridisols	Tall and short grass prairies
Aridsols (Desert)	Shrubs or sparse grasses
Entisols, Inceptisols (Mediterranean Climate	Sclerophyllous woodlands
Ultisols	Coniferous and mixed conifer/deciduous forests
Alfisols	Coniferous forest
Spodosols and associated Histosols (cold climates)	Boreal coniferous forests
Entisols, Inceptisols & associated Histosols (cold climates	Tundra vegetations (treeless)

Literature Used for Figures

Brady, N.C. 1999. The nature and properties of soils. Twelfth Edition.Prentice Hall.Dewitt, T.A. 1984. Soil survey of Story County, Iowa. USDA Soil Conc. Serv., Washington, DC.

Barnes, B.V., D.R. Zak, S.R. Denton, and S.H. Spurr.1998. Forest ecology – 4th Edition. John Wiley.

Foth H.D., 1984. Fundamentals of Soil Science. John Wiley & Sons, Inc.

Harris, R.W., J.R. Clark, and N.P. Matheny. 1999. Arboriculture – Integrated management of landscape trees, shrubs and vines – Third Edition. Prentice Hall, NJ.

Kirkham, M.B. 2005. Principles of soil and plant water relations. Elsevier.

Koslowski, T.T., P.J. Kramer, and S.G. Pallardy. 1991. The physiological ecology of woody plants. Academic Press.

Kramer, P.J. and J.S. Boyer.1995. Water relations of plants and soils. Academic Press.

Larcher, W. 2003. Physiological plant ecology – 4th edition. Springer.

Mattheck, C. 1998. Design in nature. Learning from trees. Springer.

Perry, D.A. 1994. Forest Ecosystems. John Hopkins.

Sandor, Jon 2006. Class notes from previous involvement with NREM 301

Schultz, R.C. 2006. Class notes from For 603 – Tree growth and development; NREM 407 – Watershed management and NREM 301 – Forest ecology and soils.

Thompson, J. R. 1992. Prairies, Forests, and Wetlands: The Restoration of Natural Landscape Communities in Iowa. University of Iowa Press, Iowa City, IA. 139 pp.